STRUCTURE MORPHOTYPES AND MINERAL COMPOSITION OF THE GANGA SANDS BETWEEN HARIDWAR AND RAJGHAT, UTTAR PRADESH.

By

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M. Sc (A.M.U.)

THESIS SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE
AWARD OF THE DEGREE OF

MASTER OF PHILOSOPHY

IN

GEOLOGY

AT

THE ALIGARH MUSLIM UNIVERSITY, ALIGARH

February, 1981

ALIGARH MUSLIM UNIVERSITY
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I certify that the work presented in this dissertation has been carried out by Mr. Tulsi Das, M.Sc.(AMU.), Junior Research Fellow of the University Grants Commission, under my guidance. The work is an original one and has not been submitted for any other degree at this or any other University.

B.D. Bhardwaj
(B.D. BHARDWAJ)

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CHAPTER - I

INTRODUCTION

The study of modern sediments offer an excellent opportunities for studying the processes and products in different known environments. The systematic record of the sedimentary characters can be of great help in interpreting the ancient rock sequences.

It is only in the recent past that the attention has been focussed on the modern sediments of the large river complexes. Bagnold (1960), Coleman (1969), Doeglas (1962), Fisk (1961), Frazier and Osanik (1961), Harms et al (1963), Singh (1973), McGowen and Garner (1970), Mckee (1957) Stramtewvan (1954), Leopold and Wolman (1957), Willium and Rust (1969). In contrast to meandering rivers, sandy braided streams relatively have received less attention. The well known braided streams studied include the Durance and Ardeche (Doeglas 1962), Brahmputra (Coleman 1969), Platte (Smith 1970), Tana (Collinson 1970) and South Suskatchewan (cant and walker 1978). The modern sediments under investigation are characteristically of braided fluvial environment of river Ganga between Haridwar and Rajghat in Uttar Pradesh (Fig.1).

The present investigation is an attempt to make an integrated study of various structure morphotypes, grain size-parameters and mineral composition of Ganga sediments to develop a model for braided stream deposits.

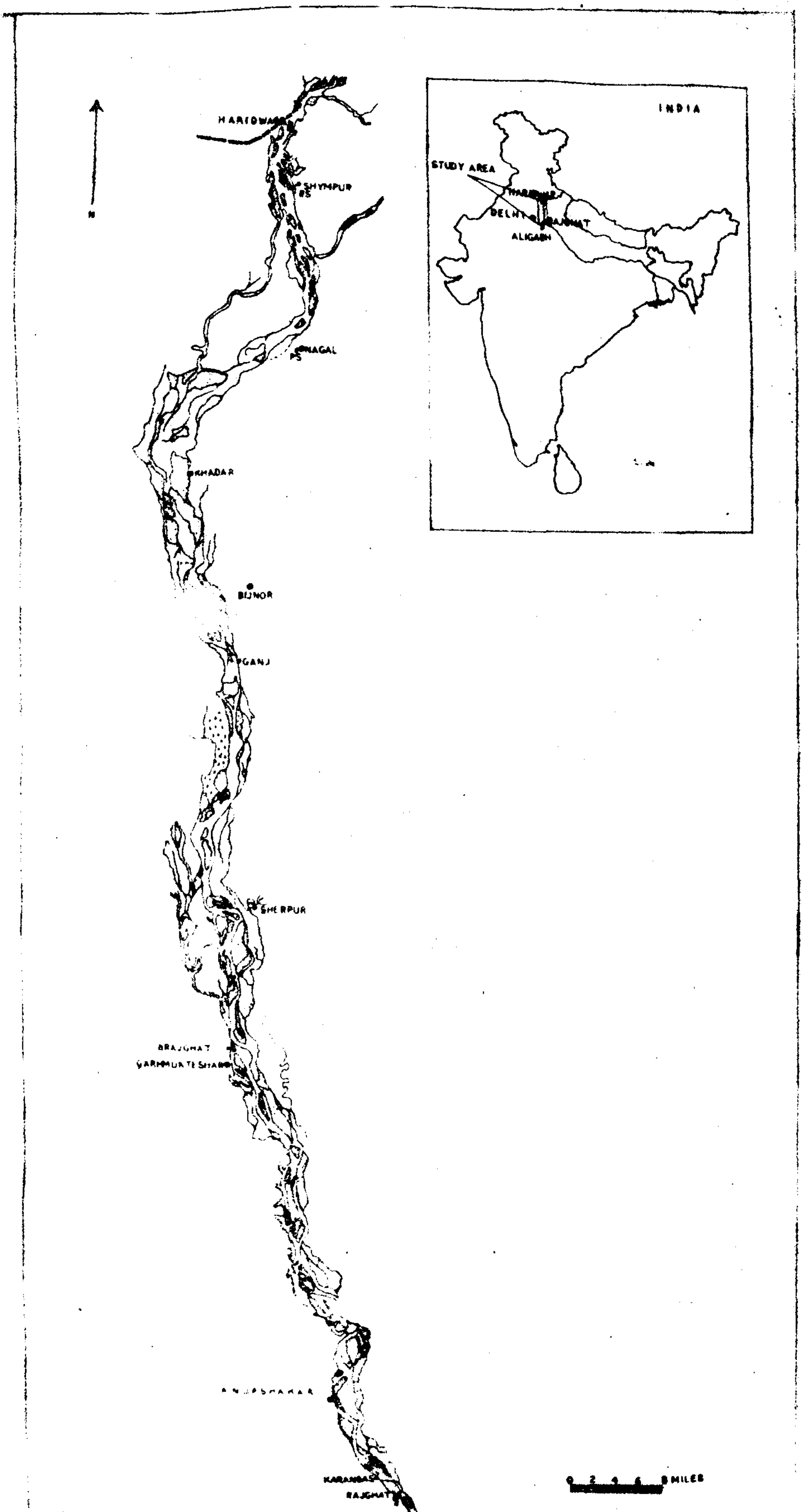

Fig. 1 MAP OF THE AREA

GANGA RIVER

The river Ganga, takes its name after the junction of the two head stream, namely- Bhagirathi and Alaknanda at Devaprayag. It originates from Gangotri glacier, north of Kedarnath at a point called Gaumukh. It flows in Himalayas before it enters into the alluvial plains at Haridwar. Here, its course swings and flow becomes roughly parallel to Himalayas in a east-west direction. The flow patterns are controlled by the weak zones in the gangatic alluvim. (Singh and Rastogi 1973).

GEOMORPHOLOGICAL SETTING

Geomorphologically, India has been divided into three physiographic divisions i.e. peninsular region lying in the south, is a triangular areaprojecting into the Indian Oceans, Extra-peninsular region-including the mountain belt of Himalayas in the north and the Indo-gangatic alluvial plain separating the other two divisions of Indian-sub-continent. Indo-gangatic plain covers an area of 85,0000 sq.km. and extend across the northern India from Assam and Bengal in the east through Bihar and U.P. to Punjab and Sindh in the west. Ganga river alongwith the other rivers of northern India forms the largest alluvial plains of the world and provide an excellent opportunity to study the fluvial processes of sedimentation. It makes an elongated basin which runs nearly east-west direction in front of great Himalayas.

PLATE-1

1

EXPLANATION OF THE PLATE

Figure-1 Shows braiding nature of the river Ganga. Dark portions are the channels containing water and the light coloured portions are braid bars.

The Ganga sediments are about 500-1000 m thick (Singh & Kumar 1977) along the foot hills of Himalayas and the thickness of the sediments decreases towards south.

During its journey from Haridwar to Rajghat, Ganga River deposits sand, silt and clay forming the bars (Transverse and longitudinal), overbank deposits and flood plain deposits (Plate 1 Fig. 1). The prominent river tarraces occur on the southern bank and extensive flood plains have been developed on the north--ern bank alongwith ox-box lakes and swamps (Singh 1977).

METHODS OF INVESTIGATION

FIELD METHODS:- The area under investigation was divided into seven sectors and the data were collected from both the banks. The method employed in the investigation was to dig trenches with the help of a showel and Khurpa. The trenches were made without proper orientation to expose the primary sedimentary structures. The depth of the trenches varies from sector to sector and also from place to place within the same sector, depending upon the height of the sand deposits made by the river during its flood period. Generally, the depth of the trenches range between 1 m to 3.5 m and the length between 1.25m to 4 m. After digging, the walls of the trenches were smoothened with the help of a knife. Then the trenches were left for drying by exposing them to air current or sun ligh. When sediments became dry, the stratifications and other sedimentary structures were visible clearly. The sedimentary structure morphotypes were examined with the point of view of their vertical and lateral relationship, lithology geometry and orientation.

Mostly, the trenches were dug to expose stratifications rougnly parallel to the flow of the river, but the stratifica--tions were also examined in three dimensions. In the case of planar cross-stratificationsthe azimuths were directly measured with the help of the clinometer compass. The thickness of the cross stratified units and the inclinations of cross-stratification planes from the horizontal were measured mostly on the A-b-plane, whereas, the azimuth of the accute bisectrix of the curved surfaces was taken as the true azimuth of the dip of foreset surfaces of the trough cross-strata.

The sand samples were collected from each locality whenever found necessary. In all, 200 samples were collected to determine the mineral composition and mechanical composition.

LABORATORY METHOD : The areaunder investigation was divided into seven sectors of various sizes in such a manner that,as for as possible, each sector contained a minimum of 150 measurements and included four to ten observation points. The data are grouped into 30° classes. The vector mean azimuth (Θ V) and Vector magnitude (L%) for each locality and sector as a whole were calculated using vector summition method (Curray 1956). The distribtuion of dip azimuth of cross-stratification foresets was plotted in the form of rose diagrams.

Twenty four representative samples were selected for grain size analyses. The size analyses were done by sieving method on $\sqrt{2}$ wentworth scale using standard set of A.S.T.M. sieves. 100 gms of sediments was taken from each sample, to avoid both irrational class limits and mid point and also to simplify the statistical computation Phi (Ø). Scale of Krumbein (1936)was followed. Data were grouped into size classes with interval of 0.5 Ø. The cumulative curves were drawn on the log probability graph paper. The statistical measures developed and defined by FolK and Ward (1957) were used to describe the characteristics of size frequency distribution.

Heavy minerals were extracted from 10 samples. The material falling in next to modal-class was taken for heavy mineral analysis. The separation was done according to the centrifuge method outlined by Tayler (1938), using bromoform of specific gravity of 2.87 as the separating liquid. The heavy mineral crop was washed with alchohal, dried, weighed and mounted permanently in Canada balsom.

Sediments were quantitatively analysed for their percentage composition. Each sample was separately spread over four rectangular sheets of smooth paper, 2 x 4 inches, together in such a way that each overlaps one half of one other and so that altogether they form a square. The pieces of paper may than be pulled apart, alternate quarters were rejected and alternate quarters combined and this process repeated as many times as necessary to obtain the desired amount of the sample. The material was mounted in Canada balsom on the slide permanently. The slide was studied using a swift automatic point counter fitted to a petrological microscope for mineral composition.

Since the opinion differed as to the total number of grains that should be counted to obtain a reliable estimate of mineral composition of the given samples (Potter and Pettijhon 1963 p.193). Successively, 200, 300, 400 and 500 grains were counted from randomly selected slides. It was found that counting of 100 to 300 grains per slide was suffieient. However, 200 grains per slide were counted for determining the modal composition of the sands.

Several methods and scales for the determination of the roundness of the grains are available (Krumbein,1941, Powers,1953, FolK,1955 and Pettijohn,1957). In the present study the roundness estimations were made for 100 grains mounted in Canada balsom on the slide, and order to ensure regular traverses, the point counting technique described by Chayes (1949) was used. One hunured detrital grains whose boundaries could be clearly distinguished were treated in each slide and the data were grouped into Power's (1953) roundness classes. An average roundness for the samples is determined by multiplying the number of particles in each by the geometric mean of that class and dividing the sum of the products by the total number of particles counted, and defined.

ACKNOWLEDGEMENTS

The writer thanks to Dr. B.D.Bhardwaj,Lecturer in the Department of Geology, Aligarh Muslim University, Aligarh, for suggesting the problem and supervising the investigation. Many thanks are extended to Prof.S.H.Rasul, Head of the Department of Geology for providing the laboratory facilities. Thanks are also due to Dr. R.C.Tewari and Messers R.Bhardwaj, Promod Kumar and D.S. Randhava for rendering help in numerous ways.

The grant of Junior Fellowship by the University Grants Commission, New Delhi is gratefully acknowledged.

CHAPTER - II

STRUCTURE MORPHOTYPES

Ganga river during its course from Haridwar to Rajghat (Downstream) deposits vast quantity of gravels, pebbles, sand, silt and clay in the form of braid bars (longitudinal and transverse) and overbank deposits. These deposits reveal a large number of primary sedimentary structure morphotypes varying in scale and geometry. The sedimentary structure morphotypes present are cross-stratifications, ripple drift cross laminations, distorted laminations (convolute laminations and wavy laminations), parallel laminations, massive unit, horizontal beddings and lenticular bedding.

CROSS - STRATIFICATION

Cross-stratification is the most commonest type of structure morphotype present in the Ganga sediments. It occurs very frequently between Haridwar and Rajghat. M ckee and Weir (1953, P 381) defined the cross-stratification as "The arrangement of layers at one or more angles to the original dip of the formation" and the cross-stratified unit as "one with layers of deposits at an angle to the original dip of the

PLATE-2

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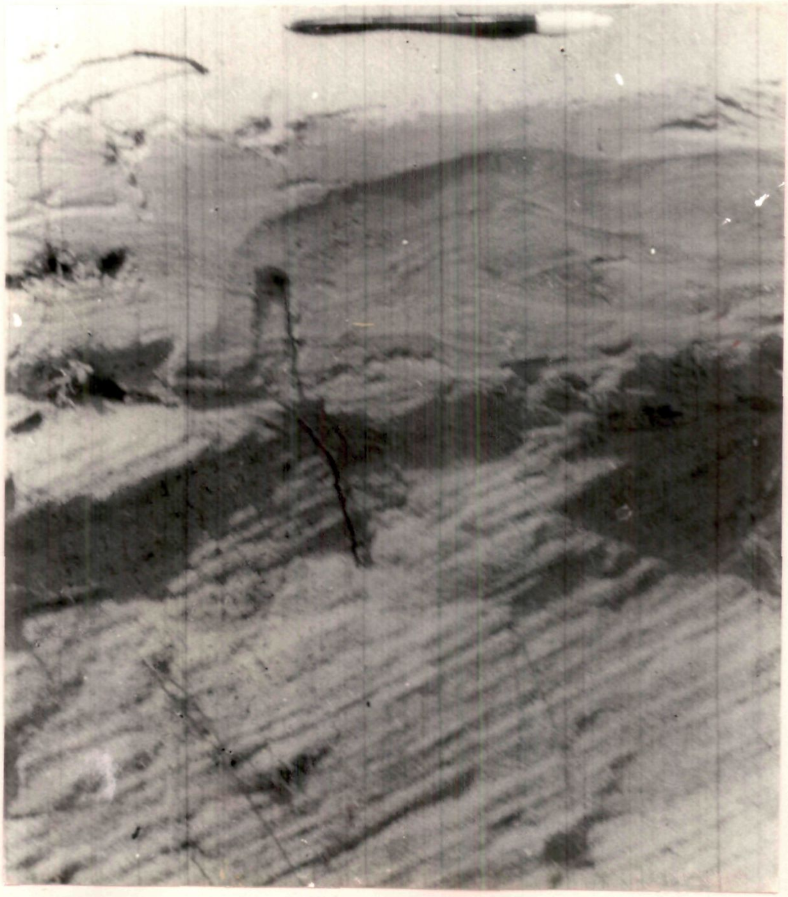

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EXPLANATION OF THE PLATE

Figure-1. Showing large scale planar cross-stratifications in sands.

Figure-2. Showing large scale planar cross-stratifications in sand having undulatory upper surface.

formation. This structure is also known by other different names in geological literature i.e. false bedding, current bedding, diagonal bedding and cross-bedding.

In the present investigation two types of cross-stratifications have been recognised, on the basis of the characters of the lower bounding surface (Mckee and Weir, 1953). Planar cross-stratifications- having more or less planar lower bounding surface (Plate 2, Fig.2) and trough cross-stratifications having curved lower bounding surface (Plate 3, Fig. 1 and 2).

The cross stratified unit shows large variation in scale. The individual sets range in thickness from few mm to 800 cm. Further, on the basis of the thickness of the cross-stratified unit, they are divisible into two types i.e. small scale cross-stratifications (thickness of the unit (<5 cm) and large scale cross stratifications (Thickness of the unit >5 cm).

PLANAR CROSS STRATIFICATION:

The planar cross-stratification is very common and has been recorded nearly in all trenches. It occurs in large scale as well as in small scale. The upper surface of the planar cross-stratified units are generally horizontal but occassionally they are undulatory (Plate 2, Fig.2).

PLATE-3

1

2

EXPLANATION OF THE PLATE

Figure-1. Showing large scale trough cross-stratifications bounded by horizontal stratifications on both sides.

Figure-2. Showing trough cross-stratifications and linguoid ripples at the surface khurpa laying parallel to the current direction.

Occurrence:- Planar cross-stratifications occur in solitary set as well as in cosets. They are commonly overlain by horizontal bedding but occassionally overlain by small scale trough cross-stratifications, ripple drift cross laminations and scouring surface (Plate 2,Fig.2). In all the trenches,the large scale planar cross-stratifications were recorded from the basal part in coarse sand. Higher up in the sequence small scale planar cross-stratified units were found associated with fine sands.

Thickness:- The large scale planar cross-stratified units range in thickness from 15 cm to 55 cm, But the units ranging from 7 cm to 12 cm are also not uncommon. On the other hand, the small scale units range from 3 cm to 5 cm. The foresets of the large scale units vary 12 cm to 75 cm. in length and those of small scale range from 6 cm to 9 cm.

Inclination:- The inclination of the planar cross-stratifications varies from 5° to 25°. In case of the large scale units, the angle of inclination is generally more than 18° whereas, in the small scale units, the inclination is less than 18°.

TROUGH CROSS-STRATIFICATION

Both small scale and large scale trough cross-stratifications occur in Ganga sediments, but the former are much more dominent and occur mostly in cosets. The cross-strata show considerable variation in their morphology and frequency of occurrences. The cross-stratifications are characterised by trough shaped erosional scours, elongated parallel to the current direction and filled with curved laminations (plate2, Fig.2).

Occurrence:- The large scale cross-strata more commonly observed to occur in single set in lower part of the sequence. Higher up in the sequence, the sands become thin bedded and characterised by small-scale with cosets of trough cross-strata. Due to the nearly horizontal deposition of the strata, the cross-strata is mostly seen in A-B plane. Traces of trough cross-strata in the plane are semi-circular. (Plate , Fig. 2) In section parallel to A - C plane, the traces of trough cross-strata are concave upwards (Plate 3, Fig.1).

Thickness:- The measurements of cross-stratifications thickness at all observation points were not possible, because suitable sections are not readily available. Despite the limitations, some observation points did provide suitable exposures where, the thickness of the cross strata could be measured. The thickness of the individual set of small scale trough cross-stratifications varies from 1.5 cm to 5 cm. On the other hand the large scale trough cross-stratified units range between 6 cm to 20 cm in thickness.

Inclination:- Sections, approximately parallel to the current direction show sets of dipping laminae of uniform thickness for a distance of several meters. The traces of laminae are nearly straight at the top and are concave upward in the lower part of the set, becomming nearly tangential to the underlying bed. Here, traces of the laminae are found to dip from 5° to 20°. The inclination in the large scale trough cross-stratifications range between 10° to 20°, whereas, the inclination range 5° to 12° for the small scale trough cross-stratifications.

MODE OF FORMATION

The review of the literature available on recent and ancient sediments suggest, that the cross-stratifications are formed by various ways. There is a general aggreement among sedimentologists that the formations of cross-stratification is controlled by current velocity, flow characteristics and the kind and rate of the sediment supply.

The literature available on this aspect shows that the cross-strata, specially, when they occur in cosets are formed by the migration of asymmetrical megaripples (Sorby,1859;Gilbert, 1899,Mc -Dowell,1957, Mckee,1957, Pelletir,1958; Allen, 1962,1963; Jopling, 1963). However, Harms et al (1975) were of the opinion that they are formed by the migration of sand-waves. On the other hand Willim and Rust (1969) were of the opinion that they produced by the migratory bar avalanche face topography. This view was also supported by Harms and Fehnestock (1965).

PLANAR CROSS-STRATIFICATIONS

Allen (1963) concluded that the cosets of the planar cross-strata are derived from asymmetrical ripples having straight and parallel c rests and, the scale of the cross-strata is governed by the amplitude of the ripples.

Observations on the planar cross-stratifications in the field as shown in Plate 2, Fig.1, suggest that the large scale planar cross-stratifications are formed by the deposition of the sand on the AVALANCHE FACE of the transverse and longitudinal bars. Here, upstream slope of these bars is gentler and the sand has migrated in the form of ripple on this slope, then slips down on the steeper slope(Down current) or avalanche face following its topography and, produced large scale planar cross stratifications. However, the small scale planar cross-stratifications were produced by the migration of asymmetrical ripples having straight and parallel crests (Allen 1963).

TROUGH CROSS-STRATIFICATIONS:- There is not general aggreement among sedimentologists on the origin of this sedimentary structure morphotype. Knight (1929), Lahee (1952) and Mackee (1957) suggested channel cutting and filling as responsible for the formation of the trough cross-stratifications. However, Sundberg (1956) related these structures to the tranquil flow rather than the shooting flow. Simon and Richardson (1961) were of the opinion that this structure develop in the upper part of the lower flow regime. Fraizer and Osmnik (1961) have suggested that the scouring of troughs is caused by eddies at the advancing front of the sandwaves. Allen (1963) concluded that small and large scale trough cross-stratifications develop from the forward migration of the linguoid and lunate asymmetrical ripples.

The development of the large scale trough cross-stratified unit in the area under investigation reveals that when the velocity of the current was high, scouring occured which was filled as there was a decrease in the current velocity. Whereas the small scale trough cross-stratifications are formed by forward migration of the trains of linguoid ripples.

RIPPLE DRIFT CROSS-LAMINATION

Sorby (1859) was perhaps the first to introduce the term 'Ripple Drift' "for all the structures that are the effect of the action of ripples on drifted material". This structure is also known as ripple laminations, ripple drift laminations, ripple drift cross-lamination, climbing ripple drift structures and a small scale pattern of cross-bedding. Hyde (1911)regarded this structure as the type of ripples, which is produced in the absence of a strong current of water moving in one direction. Bucher(1919) used this term to designate 'a small scale pattern of cross-bedding' Recently, this structure has been reported from various environments by Kindle and Bucher (1932),Twenhofel et al (1932),Mckee (1938, 1939, 1964, 1965, 1966), Kuenen (1953) Teen Haaf (1959),

PLATE-4

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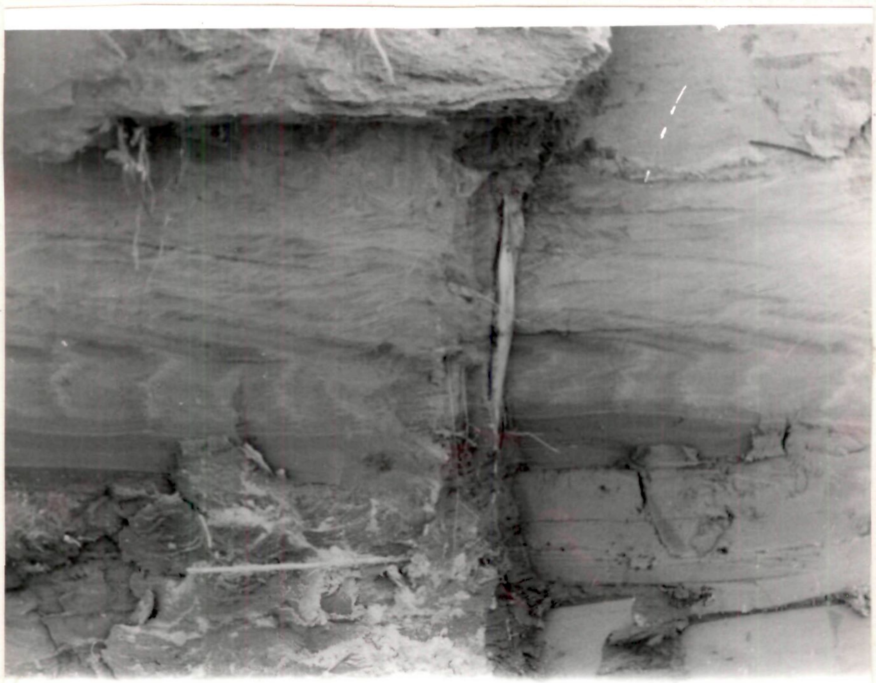

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EXPLANATION OF THE PLATE

Figure-1. Showing ripple drift cross-laminations in which the ripple laminae are in phase.

Figure-2. Showing ripple drift cross-laminations in which ripple laminae are in drift.

Coleman and Gagliano (1965), Jopling and Walker (1968), Coleman (1969), Singh (1972), Ray (1976).

In the present study, the term 'ripple drift cross lamination (McKee, 1966) has been used for a stratification in which ripple crests of vertically succeeding ripples, in section parallel to the direction of current, appear to be advancing upslope. The ripple drift cross-laminations are divisible into two types-namely Ripple laminae in phase and Ripple Laminae in drift.

Ripple Laminae in Phase:- The laminae are continuous from one ripple to another. Both the stoss side as well as lee side of the ripples are preserved. The crest of one ripple lies directly above the crest of the other with a slight shift of the crest in the direction of the current flow (Plate 4, Fig 1). The sand and silt tend to accumulate on the stoss slope while the troughs are filled by mud. Thickness of the individual units generally ranges between 3 cm to 7 cm.

Ripple Laminae in Drift:- The crest of the ripple is not directly above the other like ripple laminae in phase, but has been moved in the direction of current flow, and laminae are not continuous. The stoss side of the ripple is partly or completely eroded, leaving a surface of non-deposition. Therefore, only lee side is preserved. (Plate 4, Fig.2). The thickness of the individual sets range from 2.5 cm. to 7.5.cm. and decreases upwards. The angle of inclination range from 7° to 15°.

Depending upon the nature of the stoss side . . laminae in drift are further divisible into two types i.e. A in which the stoss side is partially eroded and consists of thin laminae as compare to the lee side laminae and, in B the stoss side is completely eroded; only, the lee side of the ripples are preserved (Plate 4, Fig.2).

Occurrence:- The ripple drift cross-laminations profusely occur in overbank deposits of Ganga river. In flood deposits, they comprised of about 70% of the total deposits. Mostly they are overlain by parallel laminations but occasionally are overlain by small scale trough cross-stratifications. Laterally, the ripple drift cross-laminations are persistent but sometimes, they pass on into convolute laminations or parallel laminations (Fig.14b). The ripple drift cross-laminations, in which the ripple laminae are in phase,gradually change upward into drift, and are generally overlain by the small scale cross-stratifications.

MODE OF FORMATION

The different mode of the formation of this structure morphotype have been proposed. Sorby (1859),Bucher (1919), Reineik (1963), Allen (1963), Walker (1963),Mckee (1964, 1966) and Jopling and Walker (1968). But they are in general aggreement that the ripple drift cross-laminations are undoubtedly produced by the upward growth of the ripples. Their formation depends upon variation in grain size, wave strength, water depth and current velocity.

The essential element in the formation of ripple drift cross laminations is the introduction of abuddance of sand and silt. When there is an adequate supply of material (sand & silt) in suspension, then the ripple marks are built upward in overlapping series rather than migrate in forward direction,

The ripple drift cross-lmaination in which ripple laminae are in phase is produced when enough sediments are available in suspension, almost no erosion of the stoss side takes place and ripples are completely burried and preserved. On the other hand the ripple drift cross-lamination in which the laminae are in drift, is formed where the current remain rather steady and receives constant supply of sediments. Hence, the ripples are drifted forward, the rate of forward progress is such that the upstream ripples climb on to the stoss slopes of the down current ripples and burried before it could be eroded completely. The eroded stoss slopes suggest considerable movement of the sediment as bed load.

All the transitions within the ripple laminae in phase and the ripple laminae in drift are known and could be interpreted as a result of increases or decreases in suspension load/bed load ratio (Jopling and Walker 1968).

PLATE-5

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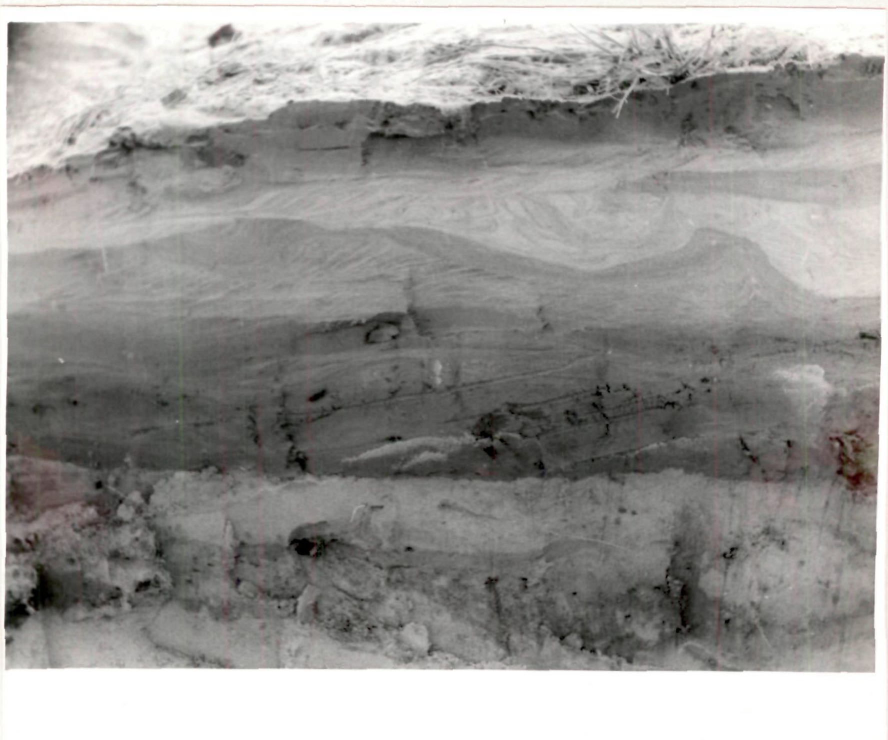

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EXPLANATION OF THE PLATE

Figure-1. Showing two types of convolute lamination.

Figure-2. Showing lateral change of convolute laminations into ripple drift cross-laminations.

DISTORTED LAMINATIONS

Distorted laminations include the structures which have been de-shaped by various processes after deposition or during deposition, but prior to compaction - Resulting structure morphotypes are described here as convolute laminations and wavy laminations. The distorted laminations are mainly associated with fine sediments.

CONVOLUTE LAMINATIONS:- There is not general aggreement among the workers regarding the term 'convolute laminations' Kuenen (1952) designated the convolute lamination as 'convolute bedding and defined as' " gradually increases upward to intensive but rather regular folds and then dies out gradually" the convolute laminations are also known as curled bedding (Fearnsides 1910), crinkled bedding (Miglorini,1950), intrastratal contortions (Rich,1950), Slip-bedding (Ksiaz-hiewiez,1951) convolute laminations (Teen Haaf 1956). He described this structure morphotype at length and defined them as "Sets of wavy or contorted laminee whose deformation characteristically dies out both upward and downward within a sedimentation Unit". Convolute laminations occurring in Ganga sediments are laminated structures whose laminae are characterised by crumpling or intricat folding within a well defined,undeformed sedimentation unit. The convolute laminations have broad and rounded synclines and sharpt crests or anticlines (Plate 5, Fig.1). On the basis of their shape and degree of folding,they have been divided into two types i.e. type A and type B.

Convolute Laminations Type - A :- The convolute laminations having broad troughs or synclines separated by anticlines. The synclines are wide and somewhat rounded, but the anticlines are pointed and generally look like a flame. The laminae are much more intensively folded into synclines and anticlines and are thinner at the crest than the trough (Plate 5, Fig.1).

The sedimentation unit, consisting convolute lamination-type - A generally ranges in thickness from 5 cm to 14 cm. Laterally they extended up to 2m to 2.5 m. stratigraphically, they are overlain and underlain by parallel laminations or ripple drift cross-laminations. Occassionally, they are overlain by small scale trough cross-stratifications. The convolute laminations sometimes, laterally change into ripple drift cross laminations (Fig.14b).

Convolute Laminations Type-B:- This also consists of synclines and anticlines but the axial planes of these folds are inclined in the down current direction. The angle of inclinations of the axial planes show variation in the same sedimentation unit. The deformational intensity of the laminee increases upward within the same depositional unit (Plate 5. Fig.1).

The thickness of the depositional unit comprising convolute laminations type-B, varies between 6 cm to 16 cm and the structure morphotype is laterally traceable upto 2 m. Generally, this type of convolute laminations are underlain by ripple drift cross-laminations or small scale trough cross-stratifications. Occasionally, B-Type convolute laminations are overlain by A-Type convolute laminations.

MODE OF FORMATION

The origin of convolute laminations is still a matter of debate. The earlier workers associated this structure with the turbidity currents. Rich,1950;Miglorini,1950, Kuenen,1953; Teen Haaf,1956; Holland,1960; Willium,1960; Sander,1960. The recent studies suggest that the convolute laminations may also occur in the environment other than the turbidity current,when the required conditions of velocity, material, loading etc. are available. The convolute laminations have also been reported from non-graded sequences (Dott and Howard,1962); M ckee and Crosby,1967; and Coleman and Ganglliano,1964). It is regarded as a common feature of flood plains and point bar deposits (Mckee,1962; Pullak Ray,1976).

The occurrence of this structure in different environments suggests various modes of their formation. (Kindle,1917; Rich,1950; Miglorini,1950; Kuhnvelten,1955; Holland,1959; Sander,1960,Willium, 1960; Mckee et al,1962; Dott and Howard,1962; DZulynski and Smith, 1963; Butryme et al, 1954; Pullak Ray,1976 and P.L.DE.Boer,1979).

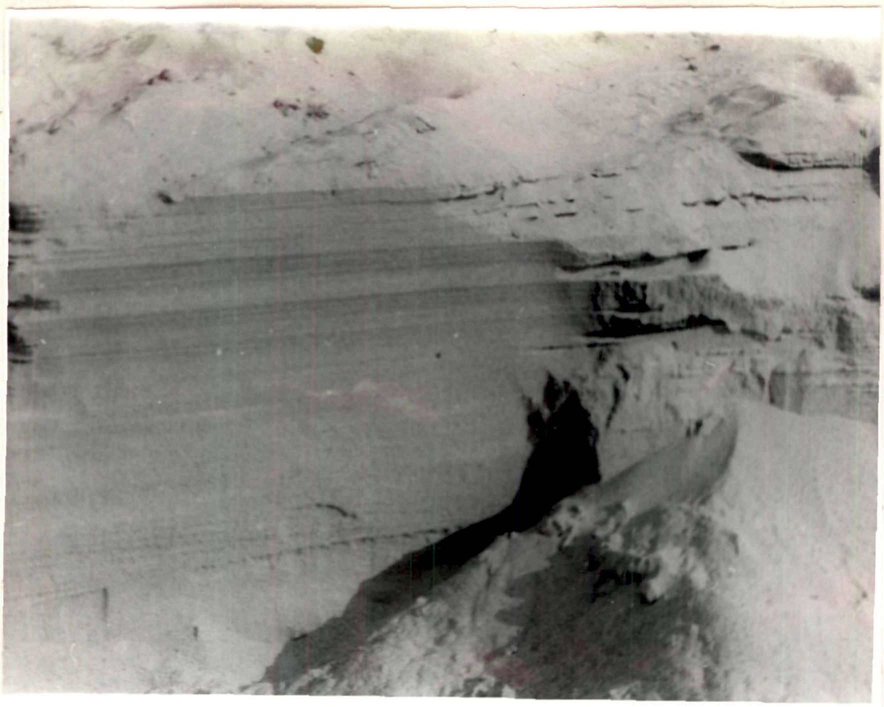
The existing literature and the observations made during the field-work suggest that the convolute laminations are complex structures and are polygenetic in nature. The nature and the shape of convolute laminations in the study area (Plate 5, Fig.1) suggest more than one mode of their formation.

The type - A convolute lamination lying between parallel laminations and ripple drift cross-lamination suggest that compaction of the lower part of the bed would lead to expulsion of the contained pore-water. The laminations of higher levels would be dragged upward into convolutions by concentration of the upheqving at definite points. Whereas, the convolute lamination type B in which the axial plains of the folds are incline in the down current direction suggests that after the deposition of the fine sediments, there was a sudden turbulence in the flow, when the sediments were in semi-plastic conditions were pushed upward giving rise the formation of synclines and anticlines having inclined axial planes in the down current direction.

WAVY LAMINATIONS

The occurrence of wavy laminations are not very common. They are limited to very fine sediments and always occur in the upper part of the sequence. The term "lamination" has been used to described all the layers or the beddings whose thickness range from 1 mm to 1 cm. (Mckee and Weir, 1953). Reinick and Singh (1973) used the term "Wavy bedding" to designate the continuous and alternating mud and sand layers Pettijohn(1975) used the term wavy bedding to the structure which is produced by rippling.

PLATE-6



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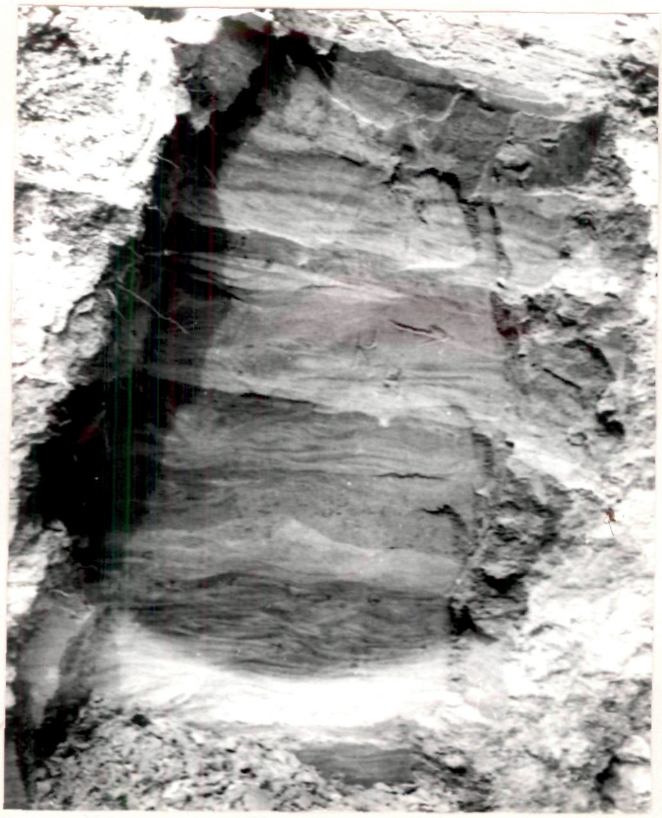

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EXPLANATION OF THE PLATE

Figure-1. Showing parallel laminations in clay and silt

Figure-2. A. Showing small scale trough sour scours (having stratifications) and

B. Showing massive units at the top.

In the present study wavy laminations have been used to describe the structure which consist of the alternating layers of different texture composition and colour in which, upper and lower limits are not straight but corrugated (Fig.11 and 12). The individual unit showing wavy laminations of variable thickness ranges between 5 cm to 15 cm or even more. The thickness of the individual laminaee ranges from 1.5 mm to 3 mm.

MODE OF FORMATION

The conditions for the formation of this structure morphotype are similar to those which control the formation of parallel laminations. The parallel laminations were formed due to the deposition of the material from the suspension under the period of quisence. As and when the parallel laminations developed, they were attacked by a variety of post depositional processes. As a result of these post-depositional processes, the parallelism of the laminations was disturbed and the laminations show wavy appearance.

PARALLEL LAMINATION

The term 'Parallel Lamination' used to describe the structure which consists sets of laminae in which individual lamination is parallel to the lower set boundary (Harms and Fehnestock,1965). This structure consists of layers showing variation in colour and texture and this structure is very common in fine sediments (silt and clay). The laminations show alternating dark and light colours (Plate 6, Fig.1).

The thickness of each laminae is always found to be less than 1 cm. The laminae having 1 mm to 2 mm thickness are very common. The units consisting parallel laminations are persistant laterally and show large varaiations in thickness ranging between 2 cm to 25 cm. The laminations are straight or in other words they do not show any kind of undulations (Fig.11,12,13,14 a & b). The parallel laminations have developed profusely in the overbank deposits around Rajghat, Garh Mukteshar and Sherpur. However, their development at Haridwar area is very uncommon. This structure morphotype commonly occur on ripple drift cross-laminations, but their occurrence above the small scale trough cross-stratifications has also been noted.

MODE OF FORMATION

This structure always occurs overlying the other structure morphotypes produced due to the migration of bed forms. Parallel laminations have been thought to be produced as a result of differential settling of the suspended material (silt and clay). At the time of deposition, the water seems to be either standing water or shows a very slow motion. Here, the competancy of water to transport the material (clay & silt) in suspension) has been rduced to great extent. The nature of this structure morphotype indicates that, when the competeancy of the current to transport the material is sufficiently decreased or the water reaches to the standing position. The material present in suspension could not be further transported by such incompetant current and settles down under the action of gravity giving rise to the formation of the parallel laminations. This mode of formation is evident by their nearly horizontal and non-erosional base.

MASSIVE UNITS

The sedimentation units do not show any visible structure are groupd here as massive units (Plate 6, Fig.2). This unit shows large variation in thickness all over the area. The individual units range in thickness from 5 cm to 30 cm. and extend laterally for tens of meters. It commonly occupy the top of the sequence and occurs nearly in all trenches.

Lithologically this unit comprises mostly clay and silt. Extensive biogenic mottling is evident in the massive units of the upper part. The clay balls and some kankar are also present. Occasionally, sand balls have also been observed. The sediment which are exposed for long period contain brown or reddish patches without any preferred orientation.

MODE OF FORMATION

The massive units are generally supposed to be post-depositional structures, Since, it is commonly occur in the upper part of the sequence, again, it is mottled and contain clay balls and kankars which are supposed to be the product of post-depositional activities. The presence of reddish or brownish patches suggest the oxidizing conditions which can only be possible after the deposition when the unit has been exposed to air above the water level. All such evidences support the view that this structure is the product of the post-depositional phenomenon.

HORIZONTAL STRATIFICATIONS

The term 'horizontal stratifications' was defined by Harms et al (1965) as "tabular sets of laminae in sand size material within which the laminae are horizontal or nearly so". The horizontal or stratified units are mostly thin bedded, ranging from 4 cm to 7 cm in thickness and are extended laterally for many tens of meters. The upper and lower boundary of the horizontal stratifications are commonly planar (Fig.11,12,13,14 a).

This structure in a stratigraphic sequence is commonly under lain by planar cross-stratifications (large scale) and overlain by ripple drift cross-laminations or small scale trough cross stratifications.

MODE OF FORMATION

The machanism for the development of horizontal stratifications is not well understood. Kuenen,1966; Pettijohn,1957 and Sandar 1965 invoke momentry fluctuations in current velocity as a sorting machanism. Jopling (1964)proposed that the down stream movement of dunes under essentially steady flow conditions may give rise to the formation of horizontal stratifications. This view has received support also from Smith (1971) and McBridge et al (1975). However, Harms and Fehnestock

EXPLANATION OF THE PLATE

Figure-1. Showing lenticular bedding having both isolated and connected sand lenses in clay and silt.

Figure-2. Showing lenticular beddings having isolated sand lenses in clay and silt.

(1965) and Sander (1965) were of the opinion that the structure is a product of the plane-bed phase of the upper flow regime. Allen (1964) concluded that the horizontal stratifications are the product of high flow regime.

The naure of this structure morphotype suggest that these are the product of the upper flow regime. The mode of formation of horizontal laminations in the upper flow regime is supported by the following evidences:-

a. The horizontal stratified units are devoid of any sedimentary structures and do not show any distinct pattern of sand distribution àlong the stratifications.

b. The sets of horizontal stratifications are commonly overlain by ripple drift laminations which are supposed to be characteristic structures of lower flow regime. Which, further suggest that at the time of formation of the horizontal strata, the current velocity was greater than that of the formation of ripple drift cross-laminations (low flow regime) which further suggest that the horizontal stratifications were developed at the time of high flow regime or in the lower part of the upper flow regime.

LENTICULAR BEDDING

This structure morphotype consists incomplete sand ripples. The ripple are discontinuous and isolated laterally look like sand lenses (Plate 7, Fig. 1 & 2). The lenticular bedding has been observed in overbank deposits. The thickness of the set comprising the laminations of clay and silt (mud) is between

5 cm to 6 cm. Each laminae of mud is 1 mm to 1.5 mm thick. The height of the ripple ranges from 1 cm to 2 cm and in length the isolated ripple varies from 16 cm to 22 cm.

This structure type occurs in the upper part of the sequences and is associated with clay and silt. The term isolated Ripples, was used by Shrock (1948) for incomplete ripples and was followed by Reinick (1961) and Allen (1968). Depending upon the nature of the sand lenses, this structure morphotype occurs in two forms Lenticular bedding with connected lenses and lenticular bedding with isolated lenses.

Lenticular Bedding with Connected Sand Lenses:- In this type, the sand lenses are continuous and persistant laterally showing variation in thickness.

Lenticular Bedding with Isolated Sand Lenses: In this type, the sand lenses are not continuous laterally, but are disconnected from each other forming isolated ripples giving floating appearance. The height of the isolated ripple or sand lenses is 2 cm and length is about 15 cm.

MODE OF FORMATION

The formation of lenticular bedding depends upon the conditions of current or wave action depositing sand alter nating with slack water conditions when mud was deposited (Reinick,1960). The nature and the association of this structure suggests that this structure can develop only in the areas where are the fluctuations in the current velocity alongwith, the appropriate quantity of fine sediments, with occasional addition of sand size material to cover the entire surface. Current or waves concentrate this meagre supply of sand into incompletely developed ripple creste in the form of disconnected ridges.When incomplete sand lenses (ripples) are formed on muddy (clay & silt) substratum and preserved as a result of deposition of next mud layer, the resulting structure is called as lenticular bedding.

TABLE - 1 : Vector mean (OV), Vector Magnitude (LX), Standard Deviation ( ) and Variance (S^2) of cross-stratification Dip azimuths.

Sector	Locality Number	Locality Level					Sector Level				
		h	OV	LX	6	S^2	n	OV	LX	6	S^2
A	1	215	207°	70.99	49.15	2415.70					
	2	80	220°	75.42	48.55	2356.96	375	206°	76.08	44.47	1977.47
	3	80	192°	95.38	17.73	314.43					
B	4	46	248°	83.60	25.29	639-42					
	5	26	210°	88.4	35.00	1242	72	235°	84.70	27	731.00
	6	36	216°	84.15	33.65	1132.46					
C	7	21	207°	72.37	17.18	295.20					
	8	57	224°	76.99	28.89	83.59	104	193°	75	41	1641.00
	9.	37	166°	77.42	28.67	821.97					
	10	10	156°	97.20	14.49	210.00					
	11	47	165°	81.32	36.74	1350					

Table-1 continue

Sector	Locality Number	Locality Level					Sector Level				
		N	OV	L%	6	s^2	n	OV	L%	6	s^2
D	12	13	194°	94.98	15.20	231.08					
	13	23	204°	96.22	16.26	264.55					
	14	36	200°	96.30	15	225.73					
	15	26	214°	96.76	14.89	221.84	78	160°	93.58	45	1970.70
	16	16	127°	42.77	49.39	2440.26					
E	17	128	134	96.91	14.49	209.83	219	148°	88.75	28.46	809.96
	18	91	168°	87.67	29.43	866.18					
B	19	170	193°	84.86	32.78	1074.44					
	20	105	160°	94.97	18.66	348.32	504	186°	85.67	31.79	1010.70
	21	229	193°	87.89	29.53	872.26					

Table-1 continue....

Sector	Locality Number	Locality level					Sector Level				
		n	OV	L%	6	s^2	n	OV	L%	6	s^2
	22	13	157°	51.01	70.32	4946					
G	23	20	174°	36.10	64.78	4196.83					
	24	33	163°	58.93	66.5	4434.75	56	156°	57.10	64	4009.50
	25	15	152°	63.62	59.95	3596.36					
	26	8	171°	66.54	53.32	2844					
	27	23	158°	64.09	58.7	3460.3					

CHAPTER - 3

FLOW PATTERNS

A review of the literature shows that the systematic measurement of cross-stratifications and other current indi--cating sedimentary structures gives the current patterns which have been prevailed at the time of deposition. Further, their study also allow to infer some of the conditions exist-ing in the basin at the time of deposition. In the present study, anattempt has been made to determine the variations in the existing flow patterns of the Ganga River.

In all 1246 measurements of the cross-stratification azimuths spread over 26 localities were made. The distribution of the dip azimuths of cross-stratification foresets are shown in Fig.2 as circular histograms. The vector mean azimuth (θ V) and vector magnitude (L%) for each locality and sector as a whole were calculated using vector summition method (Curray 1956). The results are presented in the table - 1.

VECTOR MEAN:-

Vector mean (θ V) is the most commonly used and accepted parameters dealing with orientation data (Curray;1956, Potter and Pettijohn,1963). The vector mean values determined in sector - A for three localities (Fig.2) range from 192° to 220°, that is within 40° are at locality level and at sector level it is 206°. In sector B, the vector mean was determined for two localities only and the values are 210° and 248° while for the sector it is 235°. The vector mean for six localities was calculated in Sector C. Locality level it ranges from 156° to 224° and is 193° at the sector level. In sector D, the vector mean ranges from 127° to 214° at locality level and is 160° at sector level. However, in case of sector E, the vector mean was determined for two localities only and the values are 134° and 168° at locality level and 148° at the sector level. The vector mean values in Sector F ranges from 160° to 193° at locality level and is 168° at the sector level. In sector G, vector mean dietermined for six localities ranges from 152° to 174° at locality level that is, within 22° are, but at the sector level it is 156°.

VECTOR STRENGTH

Vector strength (L%) or consistancy ratio was also calculated at locality level as well as at sector level. The vector strength ranges from 70.99 percent to 95.38 percent at locality level and is 76.08 percent at the sector level in the case of sector A. In sector B, the vector strength (L%) are 83.6 percent and 88.4 percent at locality level and 84.7 percent at the sector level. In case of the sector C, the vector strength was calculated for six localities which ranges between 72.37 percent to 97.2 percent at locality level and is 75 percent at sector level. In sector D, the vector strength ranges from 42.7 to 96.76 percent at locality level and is 93.58 precent at sector level. Whereas in Sector E, the values are 87.66 percent and 96.9 percent at locality level and is 88.75 percent at sector level. The values in sector F, ranges from 84.8 to 94.97 percent at locality level and 85.67 percent at the sector level. In the case of sector G, the vector strength calculated for six localities and found between 36.1 to 66.5 percent at locality level and 57.1 percent at the sector level.

VARIANCE (S^2) :-

The variance (S^2) of foreset dip azimuths at the sector level varies from 809 to 4009 in the areaunder investigation. These values are the indication of the scattering of dip azimuth about the mean and are numerically equal to the square of standard deviation. The variance (S^2) significantly shows large variation in the current direction suggesting that the lateral shift was very prominent and was at large scale.

Synthesis of the data reveals that the current obtained f from the orientation data, by and large coincides with the present flow direction of the river. But this is not true for all over the are under investigation. However, Ganga river shows large variation in flow pattern from those indicated by the orientation data. The reasons for such variations are the nature of the river systems prevailing at the time of the deposition of that particular cross-stratified units. The Ganga river being of the braided nature did not flow constantly in the same direction for a long distance due to the presence of bars, developed in the earlier cycle of the deposition. The river shifted its course laterally and did not maintain its previous course of flow. The presence of the thick pile of sediments suggest that this process has been repeated for many times.

Further, during the flood, water began to flow over the bank in the form of small channel. The direction this overflow was not always parallel to the main flow. The sediments deposited on the bank during floods show large variation in the current direction from the mainflow.

TABLE - 2

SIZE FREQUENCY DISTRIBUTION (PERCENT) OF GANGA SANDS

LOCALITY	Sample No.	Quantity taken in gm	DIAMETER IN PHI ( ) SCALE							
			Mesh .5 to 1.0	Mesh 1.0 to 1.5	Mesh 1.5-2.0	Mesh 2.0-2.5	Mesh 2.5-3.0	Mesh 3.0-3.5	Mesh 3.5-4.0	Mesh / 4
HARIDWAR	1	100	0.150	0.470	5.100	23.500	49.410	8.300	8.150	4.425
	2	100	0.080	0.320	3.00	9.730	49.010	12.570	15.310	9.980
	6	100	0.310	0.240	1.930	4.130	43.340	12.800	20.440	16.800
	7	100	0.350	1.700	7.750	13.650	49.500	10.030	11.300	5.720
	8	100	0.610	2.950	1.850	13.880	48.050	8.200	9.640	4.750
	9.	100	1.610	4.640	20.500	31.700	35.250	3.400	2.100	0.800
SHERPUR	10	100	2.080	14.00	44.300	18.550	17.530	1.480	1.250	0.840
	11	100	0.030	0.130	1.785	10.430	50.180	9.825	13.100	14.520
	12.	100	0.240	0.470	2.900	6.330	51.170	9.950	13.920	15.020
	13a	100	0.285	0.670	8.470	35.445	48.500	3.030	2.470	1.130
	13b	100	0.015	0.100	0.830	1.260	17.300	5.900	24.670	49.950
GARHMUKTESHAR	16	100	0.390	1.100	9.160	35.400	49.400	2.550	1.150	0.300
	17	100	0.050	0.850	37.430	35.800	23.800	1.040	0.650	0.380
	18	100	0	0.150	5.630	31.560	52.600	4.600	3.910	1.550
	19	100	3.000	8.070	25.100	28.380	30.320	1.830	2.400	0.900
	20	100	0.190	1.800	31.580	34.950	15.680	3.450	7.550	4.700
	21	100	0.140	0.250	1.000	1.700	11.450	12.560	34.300	38.600
RAJGHAT	22	100	0.325	5.400	52.00	25.200	12.000	0.960	2.350	1.760
	25	100	0.730	5.400	45.650	34.550	13.030	0.350	0.290	0.0
	28	100	0.375	1.670	17.480	28.655	40.050	4.850	5.300	1.720
	29.	100	0.015	0.240	0.900	1.280	10.720	5.100	28.020	53.625
	30	100	0.325	5.400	52.00	25.200	12.00	0.960	2.350	1.760
	31	100	0	0.050	1.350	2.480	8.650	5.450	31.170	81.150
	32	100	0.060	0.270	6.350	38.920	51.530	1.460	0.320	0.500

TABLE - 3 : Size frequency percentile parameters of Ganga Sands

Locality	Sample No.	Percentile size in Phi (0) Units							Modal Class	Fold and Word's Parameters Class			
		0 5	016	025	050	075	084	095		Mean (Mz 0)	sorting (61 0)	skewness (SK1 0)	Kurtosis (KG 0)
HARIDWAR	1	2.00	2.30	2.45	2.70	2.90	3.30	4.00		2.7666	0.5530	0.2500	1.8214
	2	2.15	2.60	2.75	2.85	3.50	3.80	4.40		3.0833	0.6409	0.4977	0.8782
	6.	2.40	2.65	2.70	3.00	3.80	4.25	4.35		3.3	0.6954	0.4736	0.7265
	7	1.80	2.30	2.50	2.70	3.10	3.60	4.10		2.8666	0.6734	0.3010	1.581
	8.	1.60	2.00	2.35	2.70	2.90	3.30	4.20		2.6666	0.7189	0.0384	1.9374
	9	1.40	1.80	2.00	2.40	2.60	2.70	3.20		2.3	0.4977	-0555	1.2295
SHERPUR	10	1.20	1.50	1.65	1.90	2.40	2.60	2.90		2	0.5325	0.2245	0.9289
	11	2.25	2.55	2.65	2.80	3.60	3.95	4.60		3.1166	0.7060	0.5303	1.0138
	12	2.20	2.60	2.65	2.90	3.70	4.00	4.60		3.1666	0.7136	0.4940	0.9367
	13a	1.85	2.20	2.30	2.56	2.65	2.70	3.20		2.4833	0.3295	-0.2185	1.5807
	13b	2.60	2.90	3.45	4.00	4.40	4.60	5.00		3.8333	0.7886	-.2303	1.0353

TABLE - 3 : Size frequency percentile parameters of Ganga Sands

Locality	Sample No.	Percentile size in Phi (0) units							Modal Class	Folk and Word's parameters			
		05	016	025	050	075	088	095		Mean (Mz 0)	Sorting (61 0)	Skewness (Sk1 0)	Kurtosis (KG 0)
GARHMUKTESHAR	16	1.30	2.10	2.30	2.50	2.65	2.70	2.90		2.4333	0.3924	-.4167	1.873
	17	1.70	1.80	1.90	2.15	2.50	2.70	2.80		2.2166	0.3916	-.8080	0.6090
	18	2.00	2.20	2.35	2.60	2.80	2.90	3.55		2.5666	0.4098	0.0420	1.4110
	19.	1.20	1.60	1.80	2.30	2.60	2.70	3.20		2.2000	0.5780	-0.3363	1.0240
	20	1.60	1.80	1.90	2.20	2.70	3.00	4.00		2.3333	0.6636	0.4166	1.2290
	21	1.60	3.10	3.45	3.90	4.25	4.40	4.90		3.8000	0.8250	-.3210	1.1770
RAJGHAT	22	1.50	1.60	1.70	1.90	2.30	2.55	3.10		2.0166	0.4799	0.4340	1.0928
	25	1.50	1.75	1.80	2.00	2.40	2.50	2.60		2.0833	0.3541	0.2120	1.3309
	28	1.60	1.95	2,10	2.55	2,80	2.85	3.65		2.4500	0.5356	-.2380	0.8292
	29	2.70	3.40	3.65	4.10	4.50	4.70	5.10		4.0666	0.6886	-.1217	1.1572
	30	2.50	2.70	2.80	3.70	4.10	4.80	4.75		3.5666	0.7409	-.4580	0.7093
	31	2.65	3.30	3.60	4.00	4.45	4.60	5.10		3.9666	0.6962	-.0890	1.1813
	32	2.00	2.20	2.35	2.50	2.60	2.70	2.80		2.4666	0.2462	-.2670	1.6393

CHAPTER - IV

GRAIN SIZE ANALYSIS

Grain size analysis was made for 24 samples distributed along the complete river length - between Haridwar and Rajghat (Fig.1). The rsults of the analyis appear in table 2. The statistical parameters calculated using the following formulae. (Fold and Ward 1957).

Mean size $$M_z = \frac{\phi 16 + \phi 50 + 0\ 84}{3}$$

Inclusive graphic standard deviation:

$$= \frac{\phi 84 - \phi 16}{4} - \frac{\phi 95 - \phi 5}{6.6}$$

Inclusive graphic skewness

$$= \frac{\phi 16 + \phi 84 - \phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 95 + \phi 5 - 2\phi 50}{2(\phi 95 - \phi 5)}$$

Graphic kurtosis:

$$= \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$$

Statistical parameters of different samples are listed in table 3. The samples collected from different localities show gradual and significant change in the down current direction.

HARIDWAR :- Of the 6 samples of Haridwar area analysed, 2 samples show the normal and unimodal distributiion while other 4 show bimodal distribution. In all the samples maximum

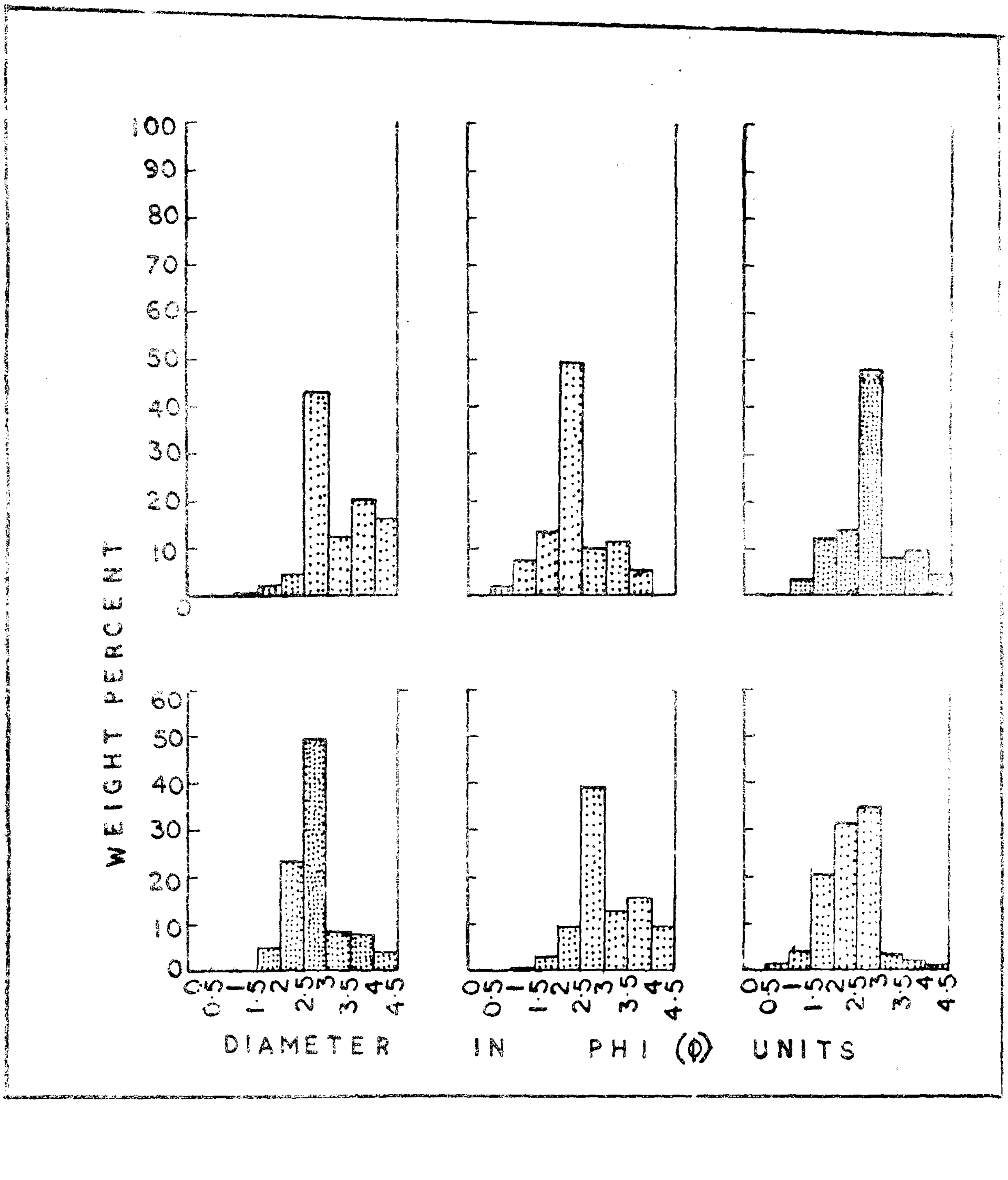


Fig. 3 HISTOGRAMS SHOWING MECHANICAL COMPOSITION OF GANGA SAND AROUND HARIDWAR

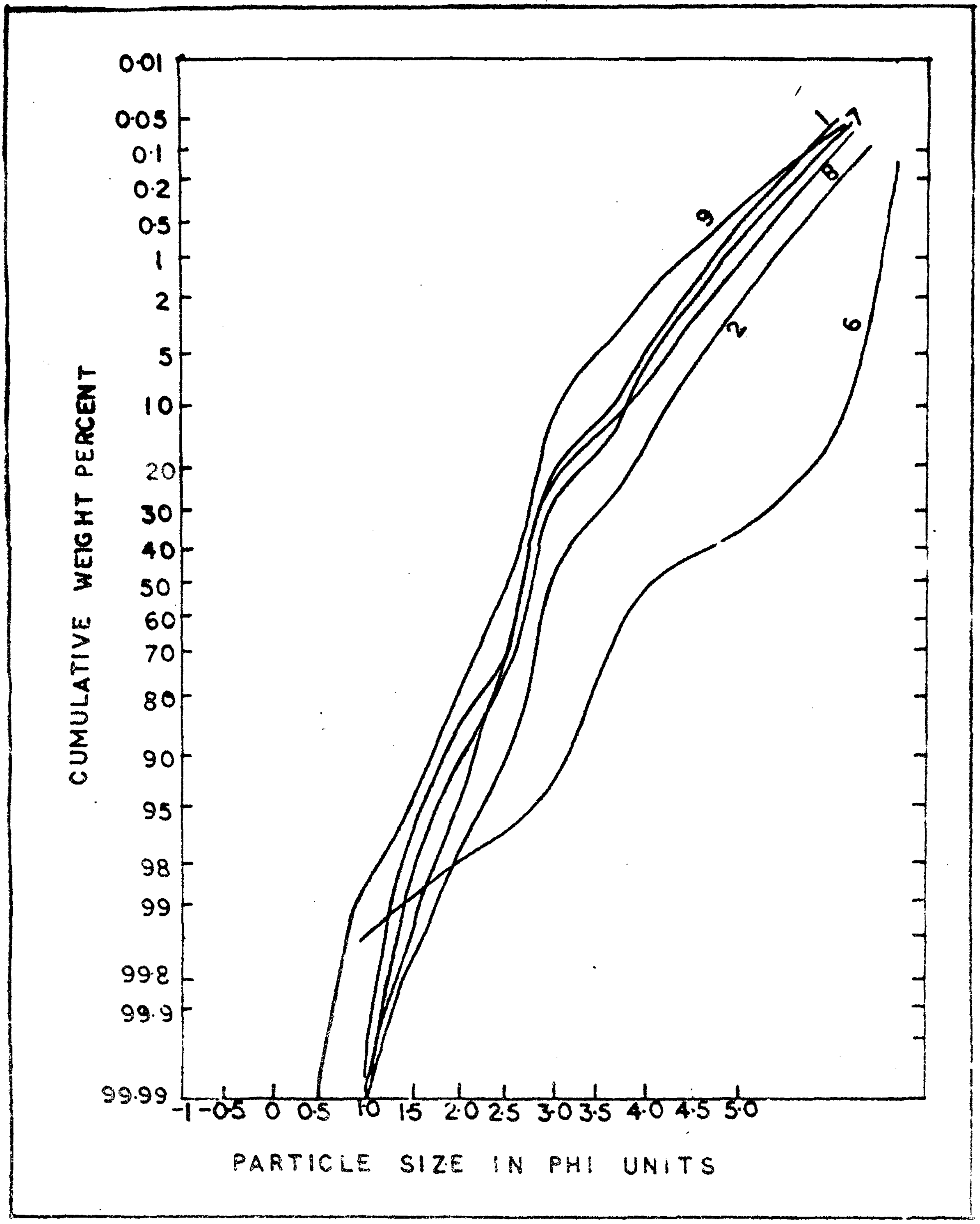


Fig. 4 CUMULATIVE CURVES SHOWING MECHANICAL COMPOSITION OF GANGA SAND AROUND HARIDWAR

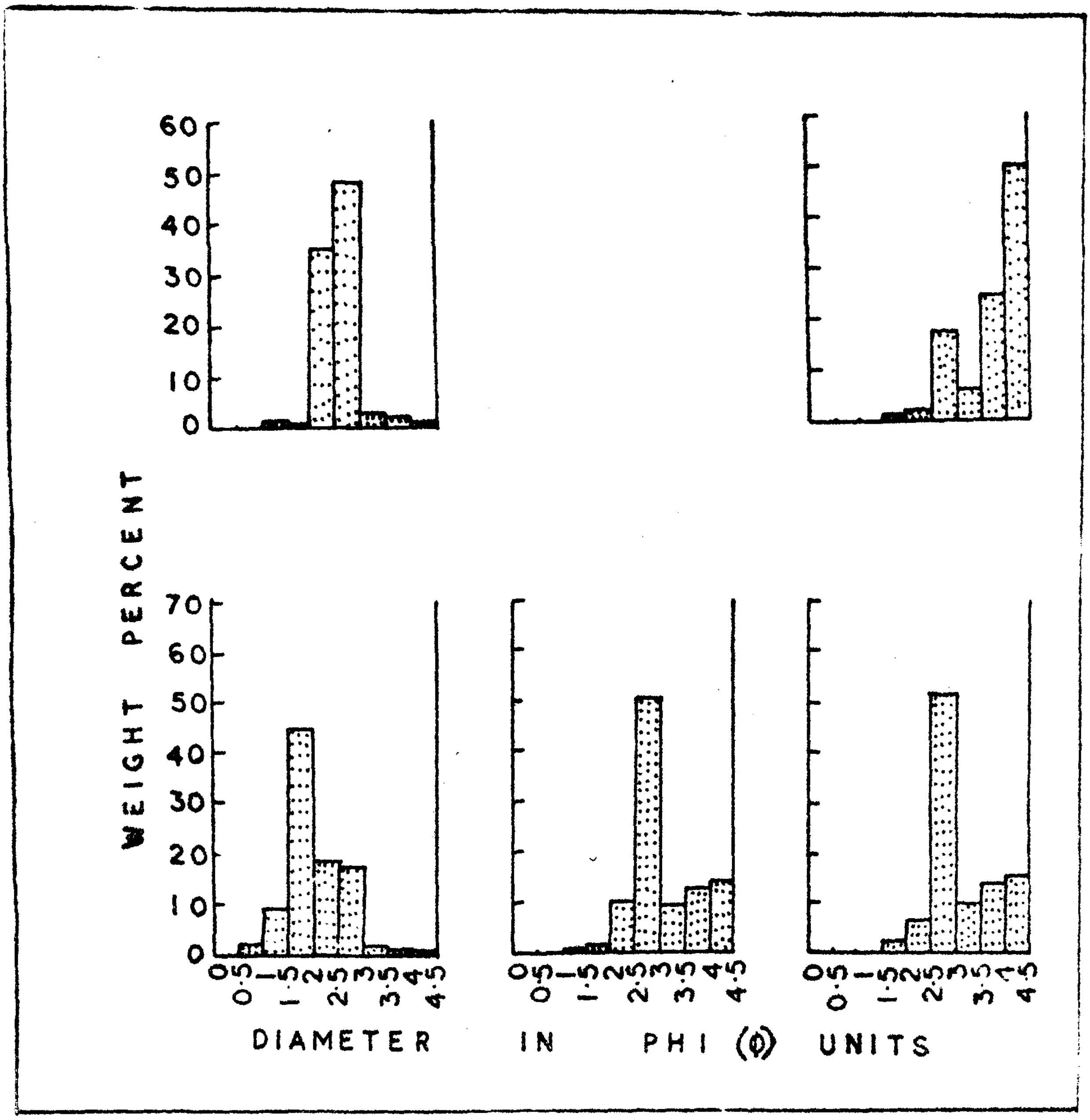


Fig. 5 HISTOGRAMS SHOWING MECHANICAL COMPOSITION OF GANGA SAND AROUND SHERPUR

sediments lie in the 2.5 ø to 3 ø size class and contains 35.25 to 49.4 percent of the total by weight. The average mechanical composition is shown in figure 3 as histogrames and in figure 4 as cumulative curves. The graphic mean size of samples varies from 2.3 to 3.3 ø, most of the samples are moderately to well sorted (5 out of 6). Only one samples is very well sorted. The frequency distribution in 4 samples is very positively skewed to positively skewed while in other two it is nearly symmetrical indicating that, by and large, the fine admixture exceeds the coarse in most of the samples. The graphic kurtosis values are highly variable and range from platy-kurtic to leptokurtic.

SHERPUR - 5 samples were analysed from sherpur area. Out of 5 samples 3 samples show bimodal distribution and the amaximum sediment lies in the 2.5 ø to 3 ø class whereas, the other two samples show unimodal distribution and the maximum sediment falls in 1.5 ø to 2 ø class and 4 ø to 4.5 ø class. the average mechanical composition is shown in figure 5 as histogrames and in figure 6 as cumulative curves. The graphic mean size various from 2 to 3.8 ø. However, the average mean size is 2.88 ø of the 5 samples analysed, 3 are moderately well sorted one is very well sorted and one is moderately sorted. The size frequency distribution in 3 samples is positively skwed while in two samples it is negatively skewed . By and large, the fine admixture is more than the coarse admixture around sherpur area. 4 samples are mesokurtic in nature and the one sample is leptokurtic.

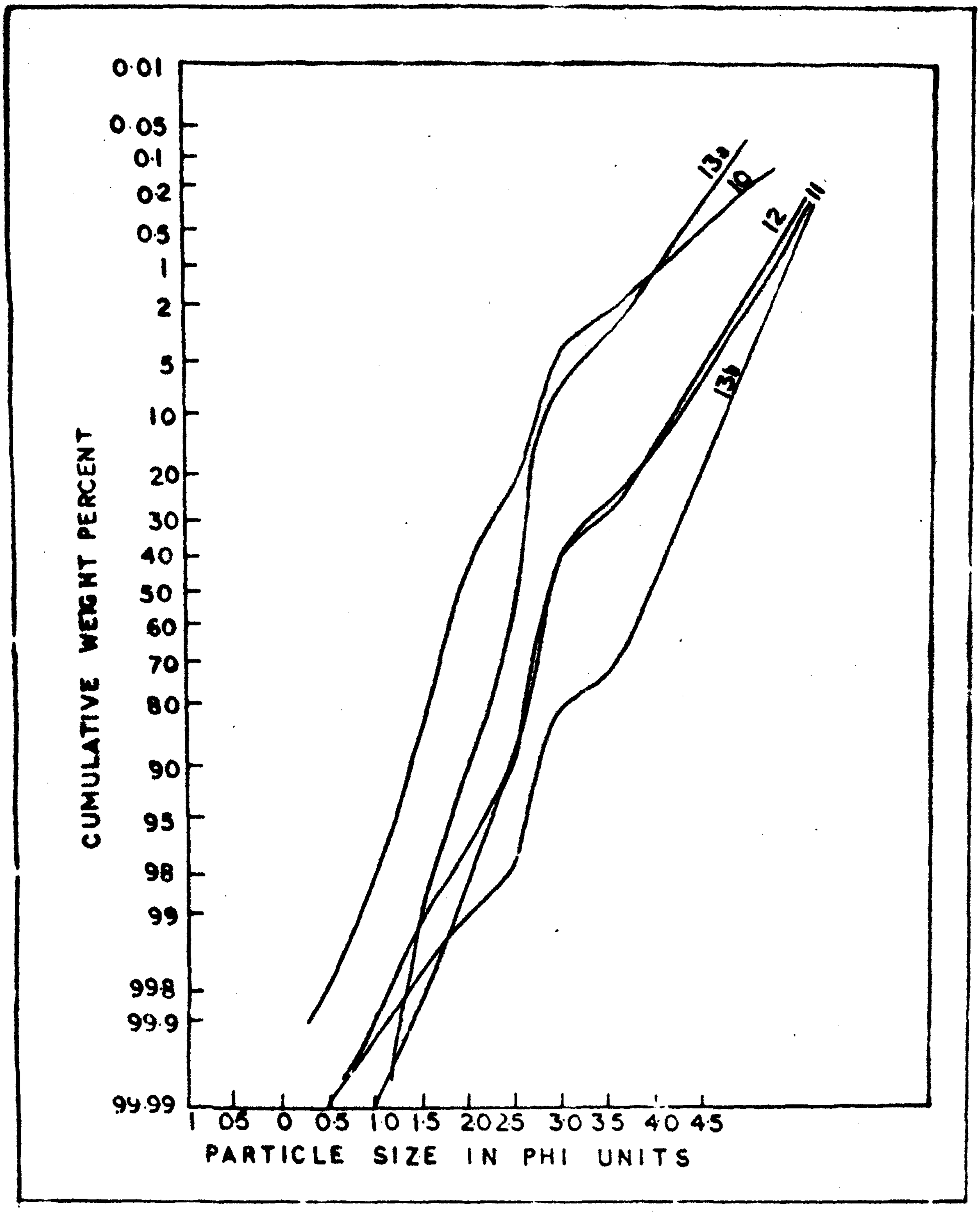


Fig. 6 CUMULATIVE CURVES SHOWING MECHANICAL COMPOSITION OF GANGA SAND AROUND SHERPUR

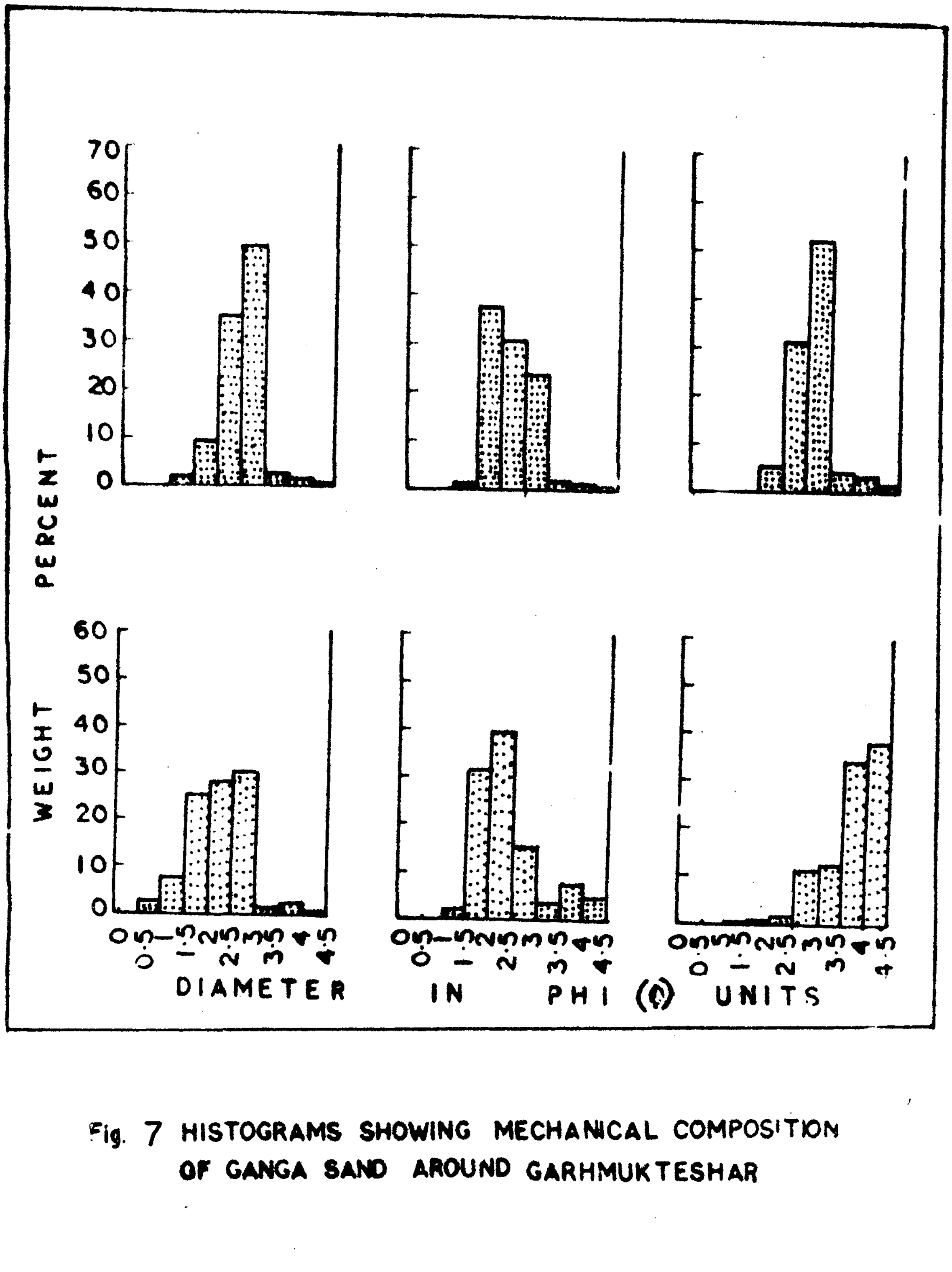


Fig. 7 HISTOGRAMS SHOWING MECHANICAL COMPOSITION OF GANGA SAND AROUND GARHMUKTESHAR

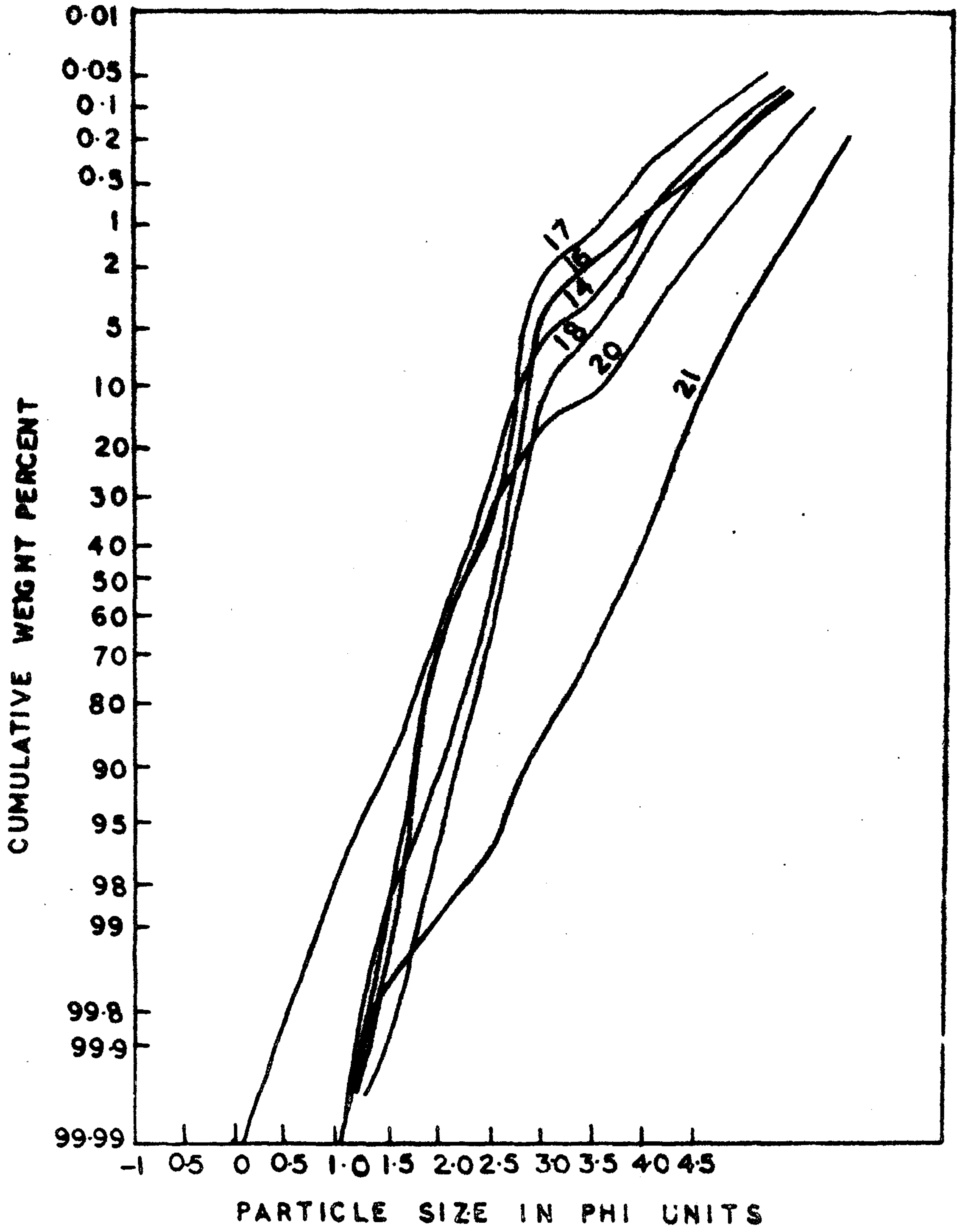


Fig. 8 CUMULATIVE CURVES SHOWING MECHANICAL COMPOSITION OF GANGA SAND AROUND GARHMUKTESHAR

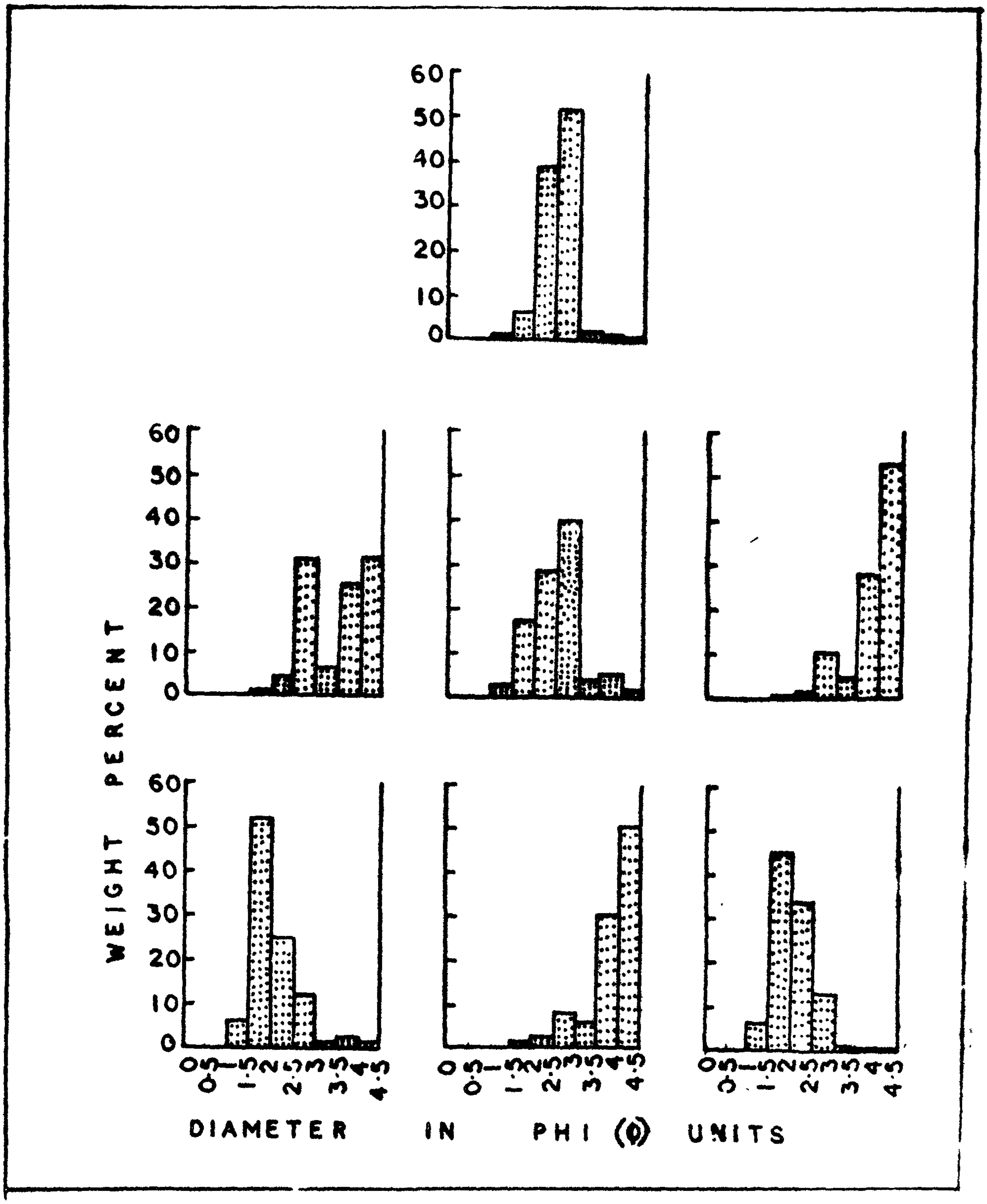


Fig. 9 HISTOGRAMS SHOWING MECHANICAL COMPOSITION OF GANGA SAND AROUND RAJGHAT

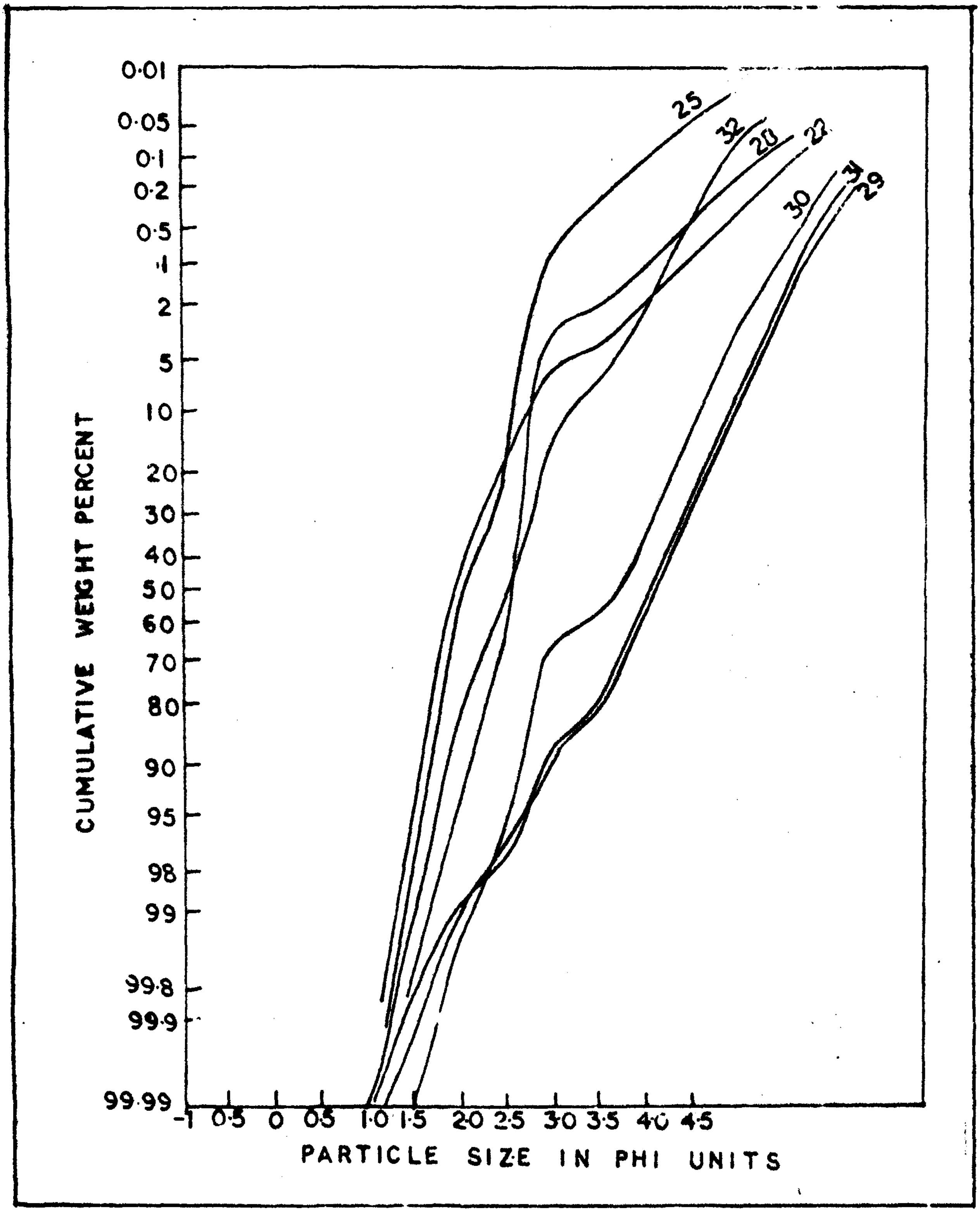


Fig.10 CUMULATIVE CURVES SHOWING MECHANICAL COMPOSITION OF GANGA SAND AROUND RAJGHAT

GARHMUKTESHAR: 6 representative samples were enalysed from Garhmukteshar area, 4 samples show unimodal distribution and 2 are biomodal. The modal class in 3 samples falls in 2.5 to 3 O class and in other 3 samples the modal class for each samples falls in 1.5 to 2 O, 2 to 2.5 O and 4 to 4.5 O class. The average mechanical composition is shown in figure 7 as histogrames and in figure 8 as cumulative curves. The graphical mean size varies from 2.2 to 3.8 O. However, the average mean size is 2.56 O. Most of the samples (3 out of 5) are well sorted. However one sample is moderately well sorted and one is moderately sorted. Of the 6 samples 4 are very negatively skewed, one is very positively skewed and the remaining one sample is nearly symmetrical. The graphic kurtosis values are highly variable. Most of the samples (4 out of 6 samples) are lepto-kurtic in nature, while others are mesokurtic and very platy kurtic in nature.

RAJGHAT:- 7 samples analysed from Rajghat area, 5 samples show biomodal size distribution while remaining 2 show unimodal distribution. The modal class in 3 samples falls in 2.5 to 3 ∅ class, in other 2 in the 1.5 to 2 ∅ class. The average mechanical composition is shown in figure 9, and as histogrames and in figure 10 as cumulative curves. The values for the graphic mean size ranges from 2.016 to 4.066 ∅ The average mean size is 2.88 ∅. Of the 7 samples analysed, 3 samples are moderately well sorted, 2 are well sorted, 1 is very well sorted and the remaining one is moderately sorted. The size frequency distribution in 3 samples is negatively skewed and the remaining 4 samples show very negatively skewed, positively skewed, very positively skewed, and nearly symmetrical distribution. The graphic kurtosis values for most of the samples (4 out of 7) range from leptokurtic to very leptokurtic. But 2 samples are platy-kurtic and the one is meso-kurtic.

ROUNDNESS OF THE GRAINS

Roundness is difinable as the degree of curvature of a particle ( ) or the degree to which a particle is without sharp corners and projections. Roundness of a particle is a physical property and depends upon the sharpness of the edges and corners. It gives and us some ideas of the distance travelled by particle prior to its deposition.

Several methods and scales for the détermination of roundness of grains are available (Wadell,1935; Russel and Tayler, 1937; Krumbein,1941; Powers,1953; Folk,1955; Pettijohn,1957) but in the present study the method developed by Powers (1953) has been followed. It consists of assigning an individual grains to appropriate Power's classes depending on the photographs with which it most nearly compares. 24 samples were analysed for roundness determination and the results are shown in table 4.

TABLE-4 Roundness data of detrital grains in Ganga Sands

		GRADE																				
		Verry angular			Angular			Sub-angular			Sub-rounded			Rounded			Well rounded			Mean roundness $Ma = \frac{p \times n}{100}$	
		p	n	pxn	p	n	pxn	p	n	pxn	p	n	pxn	p	n	pxn	p	n	pxn		
	1	0.14	8	1.21	0.21	51	10.71	0.30	29	8.70	0.41	10	4.10	0.59	2	1.18	0.84	-	-	0.2490	Angular
	2	0.14	31	4.34	0.21	92	19.32	0.30	54	16.20	0.41	20	8.20	0.59	3	1.77	0.84	-	-	0.2581	Angular
A	3	0.14	2	0.28	0.21	14	2.94	0.30	40	12.00	0.41	34	13.94	0.59	10	5.90	0.84	-	-	0.3506	Sub-angular
	4	0.14	4	0.56	0.21	21	4.41	0.30	34	10.20	0.41	31	12.71	0.59	8	4.72	0.84	2	1.68	0.3428	Sub-angular
	5	0.14	7	0.98	0.21	42	8.82	0.30	85	25.50	0.41	50	20.50	0.59	15	8.85	0.84	1	0.84	0.3270	Sub-angular
	6	0.14	8	1.12	0.21	27	5.67	0.30	32	9.60	0.41	22	9.02	0.59	8	4.72	0.84	3	2.52	0.3265	Sub-angular
	7	0.14	4	0.56	0.21	23	4.83	0.30	42	12.90	0.41	23	9.43	0.59	6	3.54	0.84	1	0.84	0.3210	Sub-angular
	8	0.14	-	-	0.21	28	5.88	0.30	40	12.00	0.41	20	8.20	0.59	11	6.49	0.84	1	0.84	0.3341	Sub-angular
	9	0.14	1	0.14	0.21	16	3.36	0.30	34	10.20	0.41	34	13.94	0.59	15	8.85	0.84	-	-	0.3649	Sub-rounded
E	10	0.14	-	-	0.21	11	2.31	0.30	26	7.80	0.41	38	15.58	0.59	22	12.98	0.84	3	2.52	0.4119	Sub-rounded
E	11	0.14	2	0.28	0.21	12	2.52	0.30	30	9.00	0.41	44	18.04	0.59	12	7.08	0.84	-	-	0.3692	Sub-rounded
	12	0.14	3	0.42	0.21	10	2.10	0.30	28	8.40	0.41	36	14.76	0.59	17	10.03	0.84	6	5.04	0.4111	Sub-rounded
	13	0.14	2	0.28	0.21	6	1.26	0.30	33	9.90	0.41	46	18.86	0.59	11	6.49	0.84	2	1.68	0.3847	Sub-rounded
	14	0.14	-	-	0.21	11	2.31	0.30	45	13.50	0.41	40	16.40	0.59	4	2.36	0.84	-	-	0.3457	Sub-angular
	16	0.14	-	-	0.21	8	1.68	0.30	40	12.00	0.41	44	18.04	0.59	8	4.72	0.84	-	-	0.3644	Sub-rounded
F	17	0.14	1	0.14	0.21	8	1.68	0.30	47	14.10	0.41	40	16.40	0.59	4	2.36	0.84	-	-	0.3470	Sub-angular
	18	0.14	-	-	0.21	3	0.63	0.30	63	18.90	0.41	32	13.12	0.59	2	1.18	0.84	-	-	0.3383	Sub-angular
	19	0.14	-	-	0.21	4	0.84	0.30	20	6.00	0.41	57	23.37	0.59	16	9.44	0.84	3	2.52	0.4217	Sub-rounded

TABLE-4 Roundness data of detrital grains in Ganga Sands

		GRADE																			
		Very angular			Angular			Sub-angular			Sub-rounded			Rounded			Well rounded			Mean roundness $Ma = \frac{p \times n}{100}$	
		p	n	pxn	p	n	pxn	p	n	pxn	p	n	pxn	p	n	pxn	p	n	pxn		
	20	0.14	-	-	0.21	9	0.89	0.30	44	13.20	0.41	37	15.17	0.59	10.	5.90	0.84	-	-	0.3617	Sub-rounded
	21	0.14	3	0.42	0.21	15	3.15	0.30	45	13.50	0.41	30	12.30	0.59	4	2.36	0.84	3	2.52	0.3425	Sub-angular
	22	0.14	-	-	0.21	2	0.42	0.30	46	13.80	0.41	48	19.68	0.59	3	1.77	0.84	1	0.84	0.3651	Sub-rounded
G	23	0.14	1	0.14	0.21	4	0.84	0.30	36	10.80	0.41	45	18.45	0.59	12	7.08	0.84	2	1.68	0.3699	Sub-rounded
	24	0.14	-	-	0.21	3	0.63	0.30	38	11.40	0.41	41	16.81	.59	15	8.85	0.84	3	2.52	0.4021	Sub-rounded
	25	0.14	-	-	0.21	2	0.42	0.30	40	12.00	0.41	53	21.73	0.59	5	2.95	0.84	-	-	0.3710	Sub-rounded
G	32	0.14	-	-	0.21	8	1.68	.30	33	9.90	0.41	50	20.50	0.59	7	4.13	0.84	2	1.68	0.3780	Sub-rounded
	33	0.14	-	-	0.21	5	1.05	.30	40	12.00	0.41	47	19.27	0.59	8	4.72	0.84	-	-	0.3704	Sub-rounded

AROUND HARIDWAR :-

9 representative samples were analysed from the Haridwar area. In 6 samples out 9, the modal class lies in the "Sub-angular" class whereas in the remaining 3 samples, in 2 it lies in the "angular" class and in one it lies in "Sub rounded" class. Modal class contains 34 to 51 percent by number of the total grains. The arithmatic mean roundness of samples varies from O; 249 to 0.365 and average 0.317. On the whole, the sediments are sub-angular except in 2 samples where they are angular.

AROUND SHERPUR :-

6 samples were analysed from the Sherpur area and the modal class falls in the "Sub-rounded" class of powers (1953). It contains 36 to 46 percent by number of grains measured. The arithmatic mean roundness of the grains varies from 0.396 to 0.412 and the average is 0.393.

AROUND GARHMUKTESHAR :-

Roundness values around Garhmukteshar area varies from sub-angular to sub-rounded. Of the 7 samples analysed, 4 are angular to sub-angular and the mode falls in the 'Sub-angular' class. The modal class contains 45 to 63 percent of the total number of the grains. The arithmatic mean roundness varies from 0.338 to 0.347 (average 0.345). In the remaining 3 samples the grains are sub-angular to sub-rounded and the modal class lies in sub-rounded class in 2 samples while, in one sample it falls into sub-angular class and contains 44 to 57 percent by number of the total grains. The arithmatic mean roundness ranges from 0.361 to 0.421 and the average is 0.38.

AROUND RAJGHAT :-

In all, 7 samples were analysed for Rajghat area. The grains are generally sub-angular to sub-rounded. The modal class in all the samples lies in "sub-rounded" class of Powers (1953) and contains 41 to 53 percent by number of the total grains measured. The arithmatic mean of roundness ranges from 0.361 to 0.402 and the average is 0.377.

TABLE 5 : Mineral composition of Ganga sands

Locality	Sample number	Model composition (Percent by number)																						
		Quartz	Mica		Chlorite	Amphibole		Garnet	Zircon	Tourmaline	Epidote	Rutile	Kynite	Feldspar		Spinel	Anatase	Titanite	Sillimanite	Apatite	Rock fragment	Zoisite	Cassaterite	Opaques
			Muscovite	Biotite		Act/Tremolite	Hornblende							Plagioclase	Orthoclase									
HARIDWAR	1	44	11	3	6	3	2	2	4	3	4	1	-	2	3	-	3	-	2	-	1	-	-	3
	2	30	29	7	-	2	1	4	7	4	2	-	-	2	4	-	-	-	-	-	7	-	-	1
	3	32	24	7	6	2	1	5	5	4	-	-	-	-	-	-	-	-	-	1	6	-	-	2
	4	39	20	6	4	4	-	9	4	3	2	-	-	-	2	-	-	1	-	-	5	-	-	-
	5	30	20	5	7	4	2	4	4	2	3	2	-	3	5	-	-	2	-	-	5	-	-	2
	6	27	19	4	3	1	-	7	5	4	1	3	1	2	10	2	1	-	-	1	5	-	-	2
	7	30	16	8	5	8	-	4	4	2	2	3	2	2	7	-	1	-	-	-	6	-	-	2
	8	31	15	8	5	5	-	6	4	3	1	3	1	-	7	-	-	-	-	-	7	-	-	3
	9	38	14	3	5	3	4	8	4	1	-	1	2	3	5	-	1	1	-	-	7	-	-	2
SHERPUR	10	30	18	4	4	3	-	4	4	4	1	4	2	3	5	-	1	-	-	1	9	-	-	3
	11	30	20	4	10	7	2	4	4	4	4	1	2	-	2	-	-	-	1	-	-	-	-	3
	12	25	22	5	5	5	1	5	5	4	5	-	-	3	5	-	-	-	-	-	6	2	-	2
	13	30	26	6	3	4	3	7	3	4	3	-	-	-	1	-	2	-	-	-	2	2	-	2

TABLE 5 CONTD.....

MINERAL COMPOSITION OF GANGA SANDS

MODAL COMPOSITION (PERCENT BY NUMBER)

LOCALITY	Sample Number	Quartz	Mica		Chlor-ite	Amphibole		Garnet	Zircon	Tourmali-ne	Epidote	Rutile	Kyanite	Feldspar		Spinel	Anatase	Titanite	Sillimanite	Rock fragment	Zoisite	Cassiterite	Opaques
			Muscovite	Biotit-e		Act/ Tremoli-te	Hornblende							Plagioclase	Orthoclase								
GARHMUKTESHWAR	14	36	13	5	6	5	-	11	3	3	-	2	2	-	-	2	-	-	-	5	-	-	2
	15	32	11	7	4	1	1	5	3	5	4	2	1	5	10	2	-	-	-	-	-	-	3
	16	43	14	4	3	5	-	1	5	3	-	5	-	2	4	-	-	-	-	7	-	-	4
	17	47	16	5	5	2	-	3	3	3	-	1	2	2	2	-	-	-	-	7	-	-	2
	18	41	18	6	5	5	1	4	4	3	-	2	-	-	-	-	-	-	2	4	-	-	3
	19	37	22	5	4	6	1	-	2	1	4	1	-	22	2	-	-	-	-	7	-	-	4
	20	39	15	3	5	3	1	8	3	3	-	2	3	-	3	2	-	-	2	7	-	-	2
	21	28	20	5	6	7	-	4	2	3	2	-	-	4	9	-	-	-	-	4	-	-	3
BRIJGHAT	22	38	17	7	4	-	-	5	10	4	-	2	1	-	-	5	-	-	-	6	-	-	5
	23	32	20	5	5	4	1	6	3	3	1	3	-	2	4	4	-	-	-	6	-	-	4
	24	25	16	10	8	-	-	4	4	5	6	-	-	1	3	5	3	1	-	7	-	-	5
	25	48	12	4	4	3	-	-	6	3	-	-	2	2	4	3	-	4	2	5	-	-	3
	26	38	16	5	1	3	1	12	3	3	-	-	-	2	3	4	-	-	-	5	-	2	4
	27	27	21	8	8	4	2	4	6	5	-	-	-	2	3	6	-	2	-	6	-	-	6

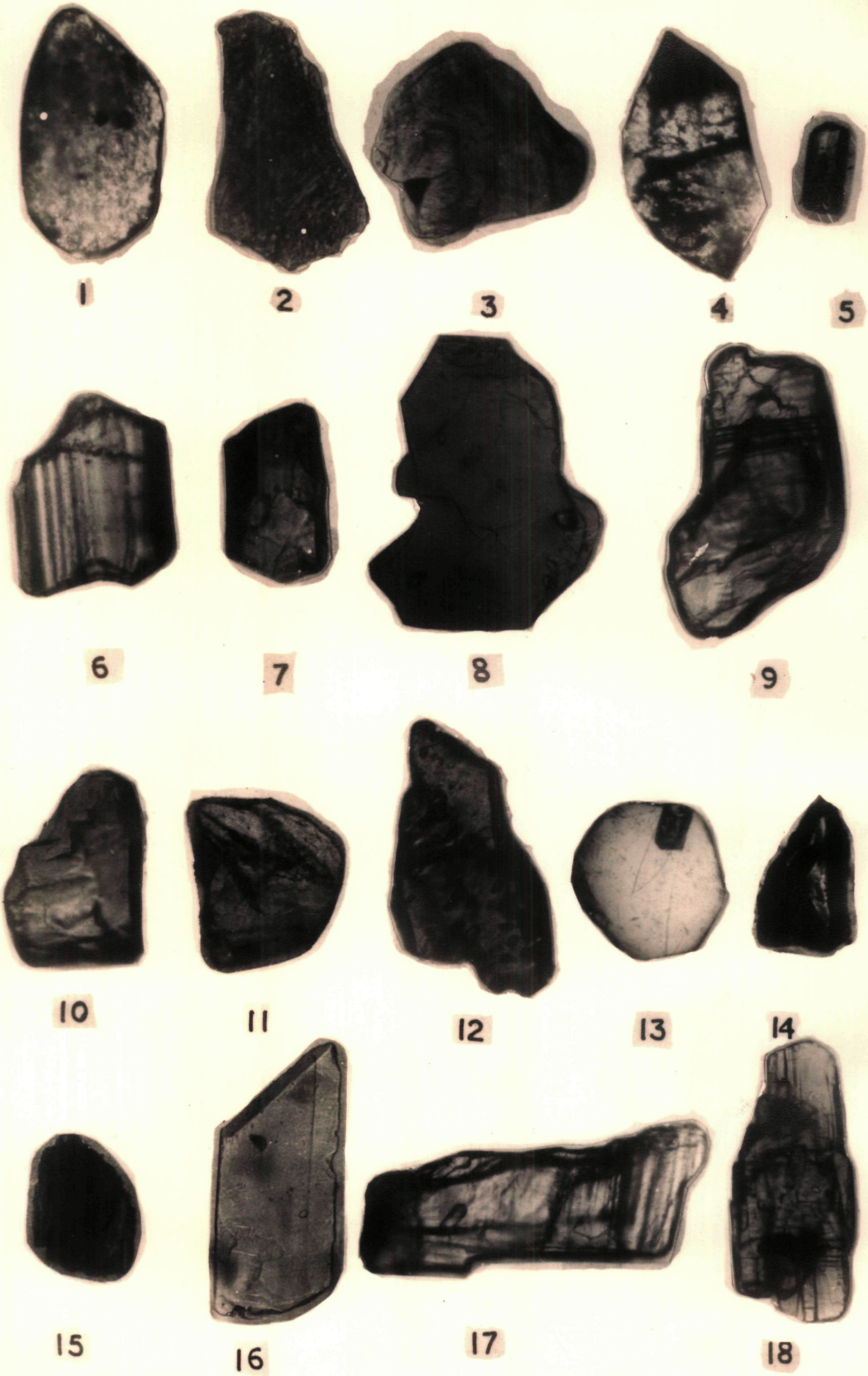
CHAPTER - V

MINERAL COMPOSITION OF GANGA SEDIMENTS

Twenty seven samples spreading all over the area under investigation, have been studied to determine the mineral composition of the Ganga river sediments. The results are shown in table 5 . Although, number of mineral species are quite large in Ganga sediments, but, except the main constituents, they occur only as scarce grains or in inclusions. Dominent, minerals present in the Ganga sediments are quartz and mica followed by a small percentage of chlorite, amphibole, feldspar and some rock fragments. Apart from these, the other minerals present in small proportions are actionalite/ Tremolite, anatase, , Casseterite, epidote. garnet, kyanite, Silliminite, rutile, spinel, titanite, tourmaline, zircon, and zoisite.

QUARTZ:- Quartz is the most abundant of all the minerals and comp rised 25 percent to 48 percent of the sediments by number. Generally, the quartz grains are sub-angular to sub-rounded but, the grains with angular and rounded outlines are also not uncommon. Roundness of the grains found to increase with the downcurrent direction. The angular grains show fractures while the sub-rounded and rounded grains are smooth surface. Generally, the grains are colourless in ordinary light and owe brilliant interference colour in the form of rings. Very commonly the grains show wavy exrinction under crossed nicols.

PLATE-8



EXPLANATION OF THE PLATE

Fig. 1 - Chlorite - pale green rounded with aggregate polarisation.

Figs.2-3- Zoisite - sub-rounded to rounded with inclusions.

Fig. 4 - Titanite - enhedral grains, sub-angular in outline marked with fractures and poor cleavage.

Fig. 5 - Rutile - prismatic form, high in relief and showing inclusions.

Fig. 6 - Plagioclase feldspar - prismatic grains with sub-rounded outlines and showing multiple twinning bands.

Fig. 7- Zircon - enhedral form and shows inclusions.

Fig. 8 - Biotite - sub - rounded flakes with zaged edges and showing inclusion of other minerals.

Fig. 9-10- Anatase - rectangular and marked with geometric patterning (Striations).

Fig.11-12- Garnet - sub-angular to sub-rounded, high in relief and is istopric. Fig.12.shows inclusions of air bubles.

Fig.13 - Apatite - rounded and showing tourmaline as inclusion.

Fig.14 - Spinel - worn octahedra and isotropic.

Fig.15 - Actinolite/Tremolite - prismatic grains, sub-angular to sub-rounded and showing cleavage.

Fig.16 - Cassiterite - prismatic showing striations parallel to the vertical axis.

Fig.17-18- Kyanite - sub-rounded, elongated and rectangular in outlines having incomplete set of cleavage.

However, few grains exhibit straight extinction. The inclusions present are of rutile, zircon, apatite and opaque minerals. Following the Empirical classification (Folk 1961) various types of quartz other than clear quartz have been identified.

(i) Quartz with straight extinction.

(ii) Quartz with undulose extinction.

(iii) Quartz grains containing numerous irregular shaped inclusions, possibly filled with either liquid or gas.

(iv) Quartz grains owing numerous inclusions of minute mineral grains i.e. tourmaline, apatite, zircon, distributed either randomly or regularly in the grains.

(v) Quartz with inclusions of rutile needles.

MUSCOVITE:-- Muscovite is more common than biotite and range from 11 percent to 30 percent by number. It occurs in the form of thin and transparent flakes . Generally the flakes are coarser than the other minerals and are flat with frayed edges. The flakes are angular to sub-angular but, some are sub-rounded in outlines and appear colourless under ordinary light, while under cross-nicols, they show low order bluish grey interference colour. The grains contain inclusions of zircon, rutile, spinel and tourmaline.

BIOTITE:-- It occurs in the form of flakes with sub-rounded out-lines (Plate 8, Fig. 8). The flakes are non-pleochroic with zaged edges. They are brownish or greenish grey in colour. Few grains of biotite have zircon and rutile needles as inclusions.

CHLORITE.-- Chlorite is not a single mineral but is a group of unseparated minerals. It occurs as flat, rounded, and irregular flakes. The flakes are pale green to dark green with black spot in colour. Grains are pleochroic in nature under crossed nicols chlorite exhibits, mass polarisation (Plate 8, Fig.1). Chlorite comparised 1 percent to 10 percent of the sediments by number.

ACTINOLITE/TREMOLITE.-- The grains are prismatic in nature with sub-angular to angular outlines bearing sub-hedral form. They are colourless to pale to yellowish green in colour. Actinolite is yellowish green in colour whereas, the tremolite is colourless and light brown with faint pleochroism low inclined extinction angle(Plate 8, Fig.15).

FELDSPAR.-- Two types of feldspar have been identified. ORTHOCLASE FELDSPAR.--- The grains are colourless and range in outlines from angular to sub-rounded. Few grains appear white in transmitted light and show aggregate polarisation under the crossed nicols. PLAGIOCLASE FELDSPAR.-- Most of the grains are colourless and prismatic in outlines. Roundness varies from angular to sub-rounded. A variety of grains show multiple twinning bands and grey colour between cross-nicols (Plate 8, Fig.6).

EPIDOTE.-- Epidote occurs in the form of prismatic and rounded grains. It show characteristically pale green or lemon yellow colour and are pleochroic in nature. The grains show identical colour under the crossed nicols as well as in ordinary light.

GARNET.- Garnet is present in various colour and form. It commonly occur as rounded grains but angular and irregular grains have also been studied. Garnet shows large variation in colour from colourless to brown, pink or red. Commonly, the grains are of high relief. Few grains show air boubles in the form of inclusion (Plate 8, Fig.11 & 12).

TOURMALINE.-- Tourmaline occurs as elongate prismatic grains. The grains are sub-angular to rounded (Plate 8, Fig.13). The most common shades of coloures exhibited by the mineral are brown, blue, pink and green. Striation are common and the mineral become extinct parallel to these Striations.

ZIRCON.-- Zircon occur as rounded grains with well marked crystal facets. However, few grains show oval forms. Zircon, shows variation in colour from colourless to pink. The grains show high relief and faint pleochroism. Inclusions (Plate 8, Fig.7) are numerous and are either of gases or of minerals .

RUTILE.-- Rutile, commonly found to occur as elongate prismatic forms with rounded pyramidal ends but, sometimes it occurs in the form of needles. Most of the grains are of yellow or red colour. The striations are parallel to the prism faces. Grains are of high relief which is characterised by a broad and dark boarder around the grains and show parallel extinction. Inclusions are common.

KYANITE.-- The grains are commonly elongated and are sub-angular to sub-rounded with rectangular outlines. Generaly the grains are colourless but few grains show blue colour (Plate 8, Fig. 17-18). Grain are pleochroic with inclined extinction. There is a step like change in interference colours.

SILLIMINITE.-- The grains are colourless and prismatic with irregular outlines. They range from sub-angular to sub-rounded and are striated and show parallel extinction.

TITANITE.-- Commonly the grains are irregular in shape but few grains are enhedral in outlines. Generally they are colourless. However some grains show yellow colour with faint pleochroism (Plate 8, Fig. 4).

ZOISITE.-- Commonly occur in prismatic form with two set of cleavages. There are grains showing well rounded boundaries. The colour varies from brown to greenish brown but, the colourless grains are also present. They show blue interference colour (Plate 8, Fig.1 & 2).

APATITE.-- Mostly grains are colourless with rounded outlines but elongated prismatic forms have also been noted. It occurs as inclusions.

ANATASE.-- The grains are rectangular in out lines and marked by 'Geometrical Patterning, are of pale yellow in colour striations (Plate 8, Fig. 9-10). Roundness of the green ranges from sub-angular to sub-rounded.

SPINEL.-- Occur as rounded grains to slightly worn octahedra. The grains are either colourless or light pink in colour. They are isotropic in nature (Plate 8, Fig. 14).

OPAQUE MINERALS.-- Beside the above minerals. There are few grains which remains dark in plane polarised light. These are opaque minerals and constitute 1 to 6 percent by number.

ROCK FRAGMENTS.-- The rock fragments constitute 2 to 9 percent of the Ganga sediments by number. The most common rock fragments are of various schists, gneisses and quartzites. However, some fragments of phyllite have also been observed.

CLASSITERITE.-- The grains of casseterite are of prismatic habit and enhedral in shape with indistinct cleavage under ordinary light (Plate 8, Fig. 16). Most of the grains are colourless to yellowish brown and bear piquent pleochroism. They show grey interference colour under cross nicols. Some grains have inclusions of other minerals.

INDEX TO THE FIGURES

For Sedimentary structure morphotypes

A. - Large scale planar cross-stratification

B. - Large Scale trough cross-stratification

C. - Small scale planar cross-stratification

D. - Small scale trough cross-stratification

E. - Horizontal stratifications

F. - Ripple drift cross-laminations

G. - Parallel laminations

H. - Convolute laminations

I. - Lenticular bedding

J. - Wavy laminations

K. - Massive unit

For Lithology

S - Sand

SCS - Sand, Clay and Silt

CS - Clay and Silt

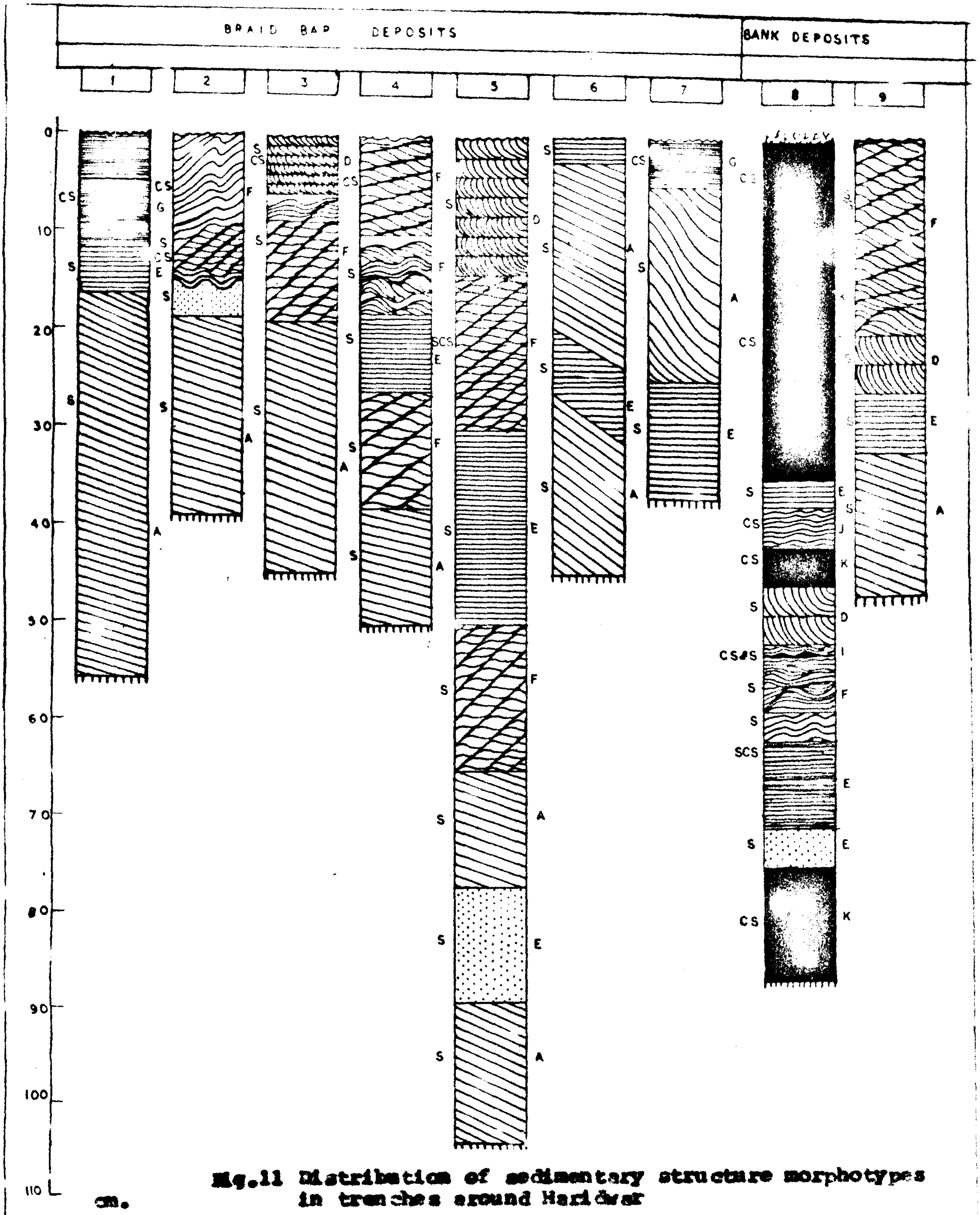


Fig.11 Distribution of sedimentary structure morphotypes in trenches around Haridwar

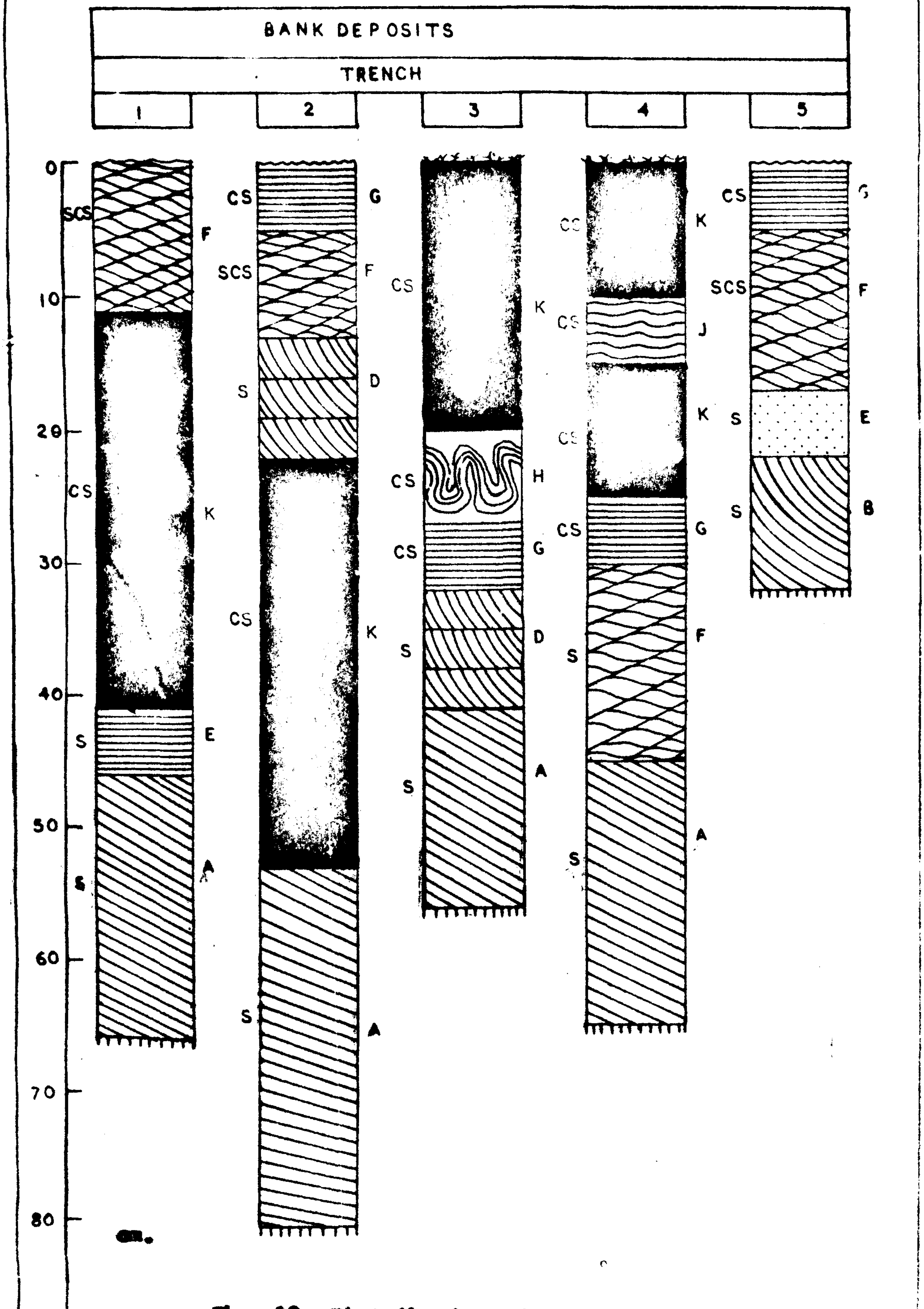


Fig. 12 Distribution of sedimentary structure morphotypes in trenches around Sherpur.

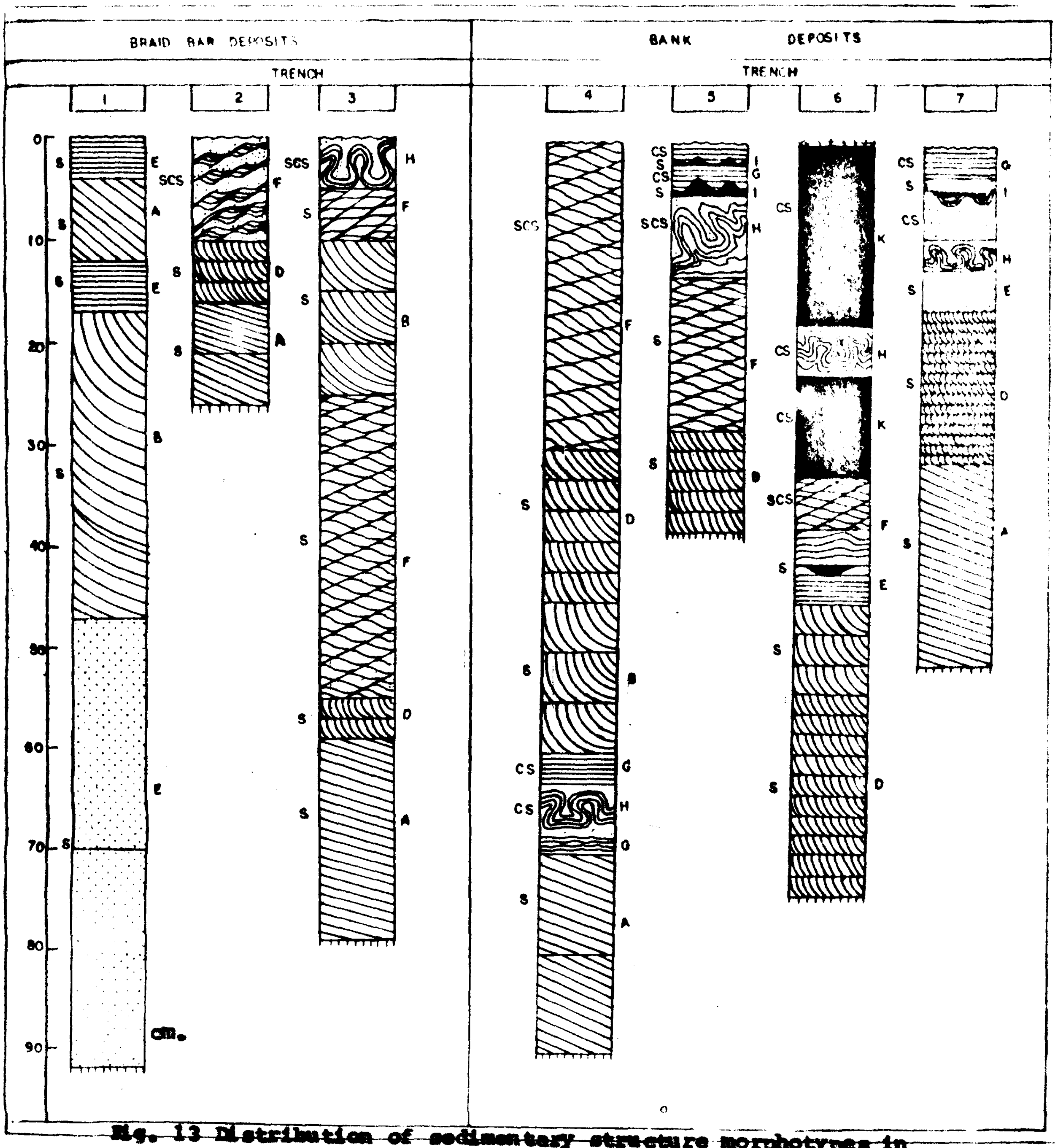


Fig. 13 Distribution of sedimentary structure morphotypes in trenches around Garhmukteshar

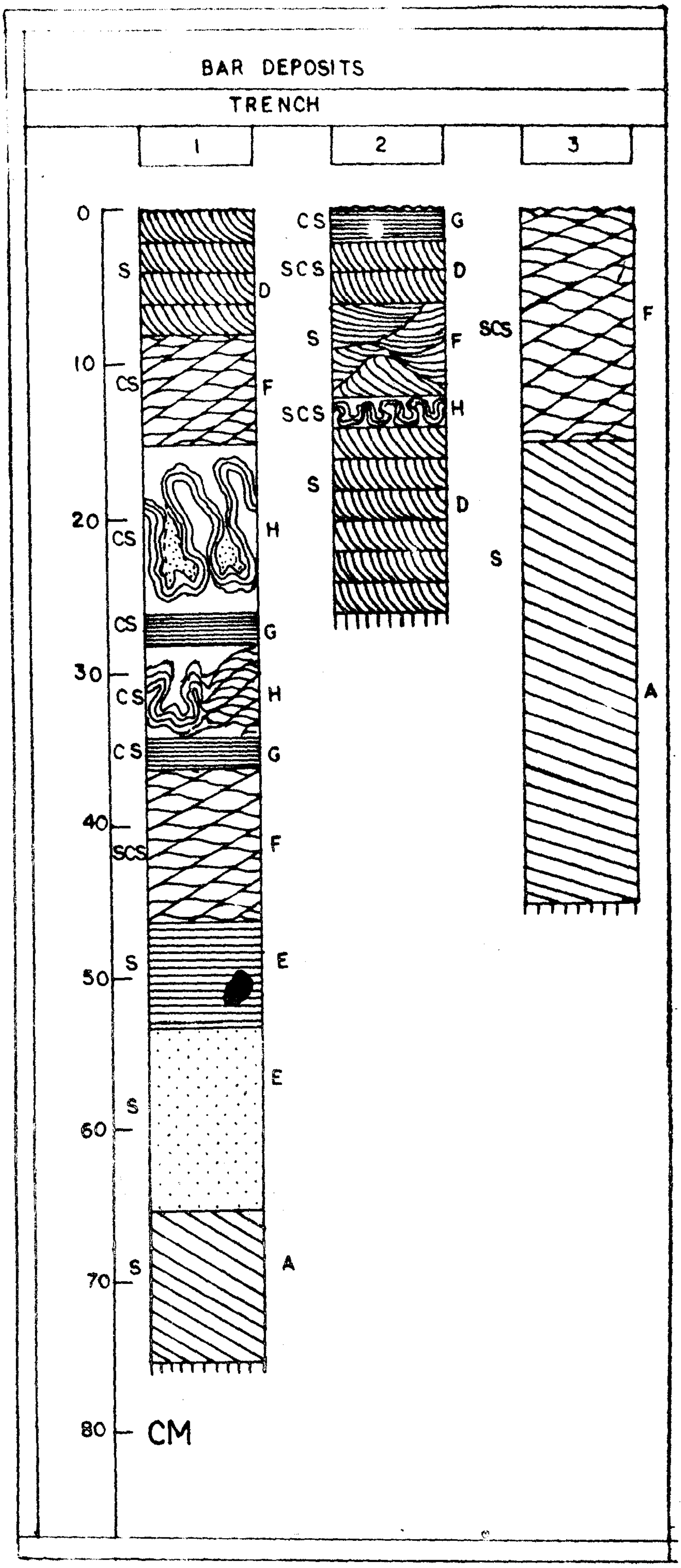


Fig.14 a - Distribution of sedimentary structure morphotypes in trenches around Rajghat

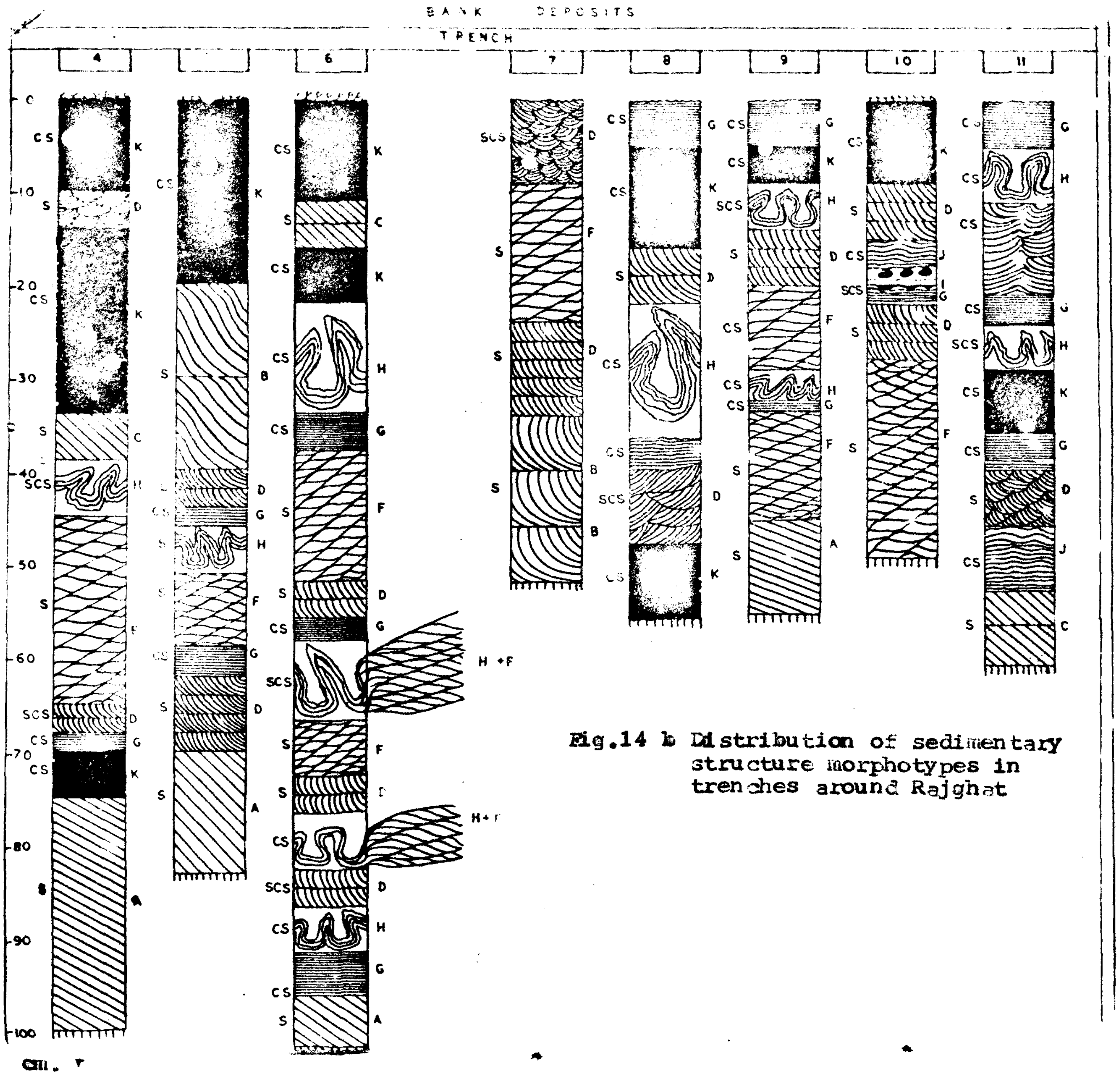


Fig.14 b Distribution of sedimentary structure morphotypes in trenches around Rajghat

CHAPTER - VI

DEPOSITIONAL MODEL

The review of the analysis of geomorphological features, sedimentary structure morphotypes, stratifications and stratigraphic sequences developed in side the channel bar (CA) and on the bank's (V/L AC) deposits of Ganga river, reveals a systematic development of structure morphotypes (Fig.11,12,13,14a and 14b).

Of the fifty trenches dug, 9 were taken as representative 7 from the braid bars, 2 from the bank deposits from the Haridwar area. In all the trenches of braid bar deposits, the basal part as represented by the sedimentary strucutre morphotype comprising planar cross-stratifications. Out of the 7 in the 4 trenches, this structure morphotype is overlain by ripple drift cross-laminations, whereas in other 3, the planar cross-stratification morphotype is overlain by horizontal laminations (figure 11). Generally, this feature is found to be repeated i.e. horizontal laminations overlain by ripple drift cross-laminations. However, the trenches dug along the river banks showed different features. The presence of large scale planar cross-stratification is marked in the sandy bed. The overlying clay and silt, representing the emergent tops consist small scale trough cross-stratifications, ripple drift cross-laminations, parallel laminations with lenticular bedding and wavy laminations in a vertical order and finally with silty and muddy vertical accretional deposits with roots of present day flood plain vegetations (Fig.11).

Coming down towards Sherpur where the river does not show any bifurcations, the trenches were dug on both the banks. Out of 20 trenches, 5 were taken as representatives. The sedimentary structure morphotypes developed in these trenches are more or less similar to the structure morphotypes developed in the bank deposits at Haridwar area. Of the five, 2 trenches show that the large scale planar cross-stsatification is overlain by ripple drift cross laminations and massive unit comprising clay and silt with concretions (Fig.12).

Further, inodown current direction in Garhmukteshar area, out of 30 trenches, 6 were taken as representative. Out of 6 trenches 2 were from the braid bars and 4 from the banks dposits. In contrast to channel deposits, bank deposits cover wide areas, that is the width of the river goes about 2 kms. The trenches from the brid bars show large scale planar cross-stratifications at the base, overlain by small scale trough cross-stratifications followed by ripple drift cross laminations at the top. The ripple drift cross laminations pass into convolute laminations laterally (Fig.13).

The overbank deposits which generally are the product of the floods (vertical accretion) show various cycles of structure morphotypes starting with large scale planar cross stratifications overlain by small scale trough cross-stratifications, ripple drift laminations, parallel laminations in ascending order. Higher up in this sequence in clay and silt occur convolute bedding with occasional development of lenticular bedding.

In contrast to the other areas, around Rajghat, the river shows that considerable channel shifting has been occured. There are number of braid bars which are transverse and longitudinal. Only 3 trenches out 10 were taken as representative from the briad bar deposits which show in all the cases large scale planar cross-stratifications at the base followed upward either by massive sand or small scale trough cross-stratifications. They are inturn overlain by ripple drift cross laminations and alternating thin layers of fine sand and clay showing convolute laminations (Fig. 11 a) The cycle of structure morphotypes starting with large scales planar cross - stratifications at the basal part and ending with small scale trough cross-stratifications or sometimes by ripple drift cross-laminations is not uncommon.

About 30trenches dug on both the banks, but only 6 trenches showing various features have been presented in the Figure 14b. The bank deposits show a variety of sedimentary structure morphotypes representing varous flood cycles. In all the cases,

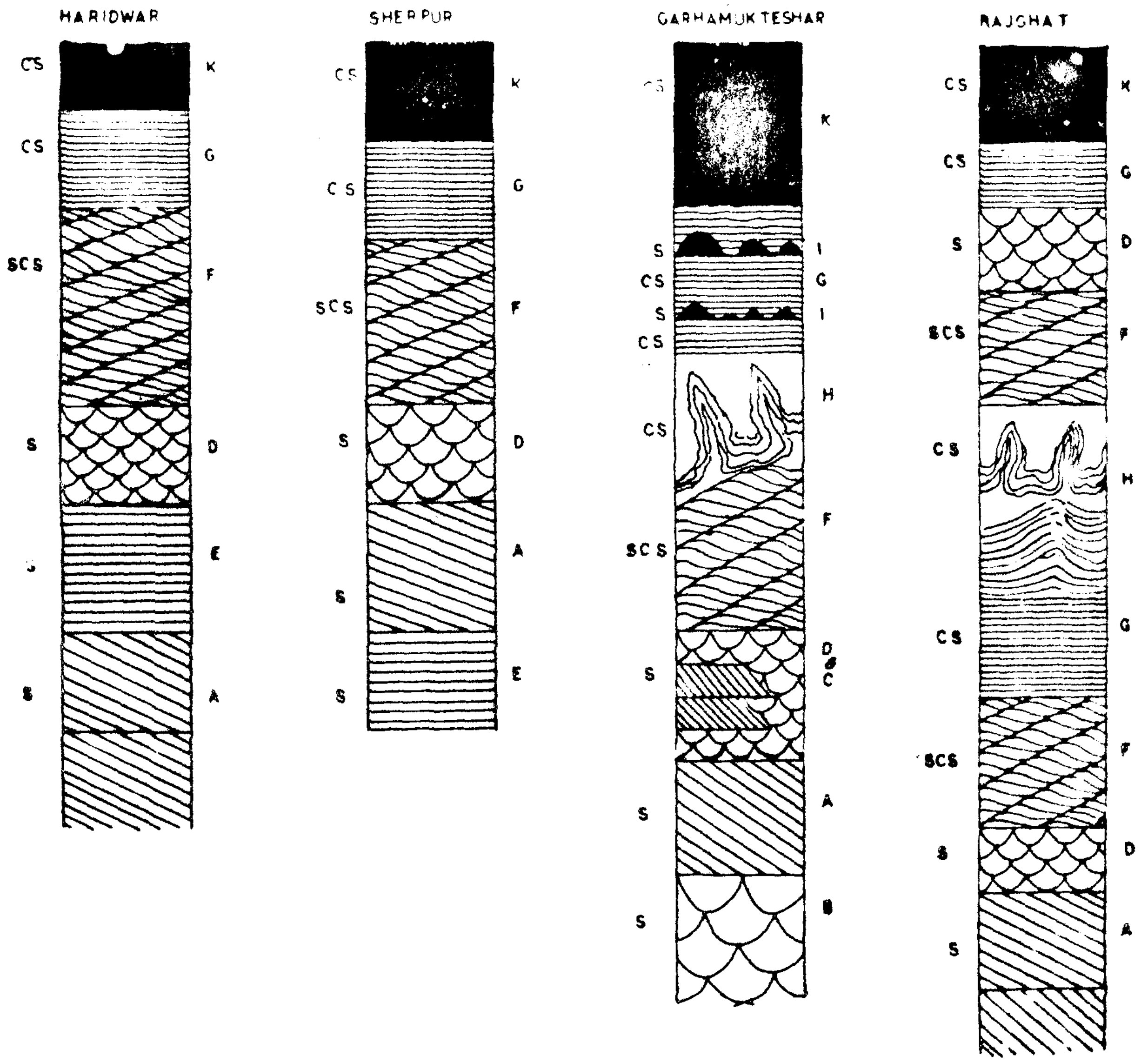


Fig 15 : GENERALISED SEQUENCES SHOWING FORMATION OF SEDIMENTARY STRUCTURE MORPHOTYPES the basal part is marked by large scale planar cross-stratifications followed upward by horizontal laminations or large scale trough cross-stratifications and wavy laminations. These structures are present mostly in the sandy beds. Towards the top the overlying sediments comprising of clay, silt and fine sands contain convolute laminations, small scale trough cross-stratifications, ripple drift laminations, small scale trough cross-stratifications, ripple drift laminations, parallel laminations and lenticular bedding with massive muddy unit at the top.

The nanalysis of the sedimentary structures, geomorphic features and stratification sequence of the recent deposit of Ganga river suggest that the deposits are divisible into two i.e. the briade bar deposits and the bank deposits. The braided aspect of the Ganga river is due to the bar deposits separating the channels. The bar deposits are the products of channel aggradition whereas the bank deposits represent mostly the flood deposits (vertical/lateral accretion deposits.)

Various sedimentary structure morphotypes developed in the Ganga sediments between Haridwar and Rajghat suggest a set of structure morphotypes for each locality. A generalized sequence showing the order of formation of various structure morphotypes have been prepared for each locality (Fig. 15).

The variability of the sedimentary structures in the sedimentation unit characterised by a particular morphotypes poses problem in establishing a genetic sequence of the structures, as a full sequence is not found to be preserved under the area of investigation. However, an attempt has been made to construct suitable models for a braided river system. On the basis of the sedimentary structure morphotypes and lithology of the deposits, two separate depositional models - A for bank deposits and the B for braided bar deposits have been developed.

MODEL - A

This represents the sequence of the structure morphotypes developed in the bank deposits of Ganga river. The basal part of the model shows scouring intrupted by large scale planar corss-stratifications. These stratfifications overlain by small scale cross stratifications of planar as well as trough types. This morphotypes followed upward by ripple drift cross-laminations and inturn by parallel laminations. Further they were overlain by convolute laminations and in turn by parallel laminations marked with lenticular bedding. This structure passes upward into wavy laminations. The top of the sequence is marked by massive clay and silt having concretions and reddish spots with some rootlets. The sequence begin with the scouring and ends with massive clay traps. This model clearly reflects the fining upward sequence,the basal part of the sequence shows coarse sand while fines are confined towards the upper part. The various sedimentary structure morphotypes occuring in the sequence from base to top, indicate the existance of the different flow regime at the time of their development. Basal Scouring and large scale cross-stratifications indicate high velocity of the current. As we go higher up in the sequences, the velocity decreases, resulting in a progressive decrease in the scale of the cross-stratifications. A further fall in the stream power is reflected by the overlying ripple drift cross laminations and parallel laminations. The presence of convolute laminations do not show any current significance in the sequence but are revealing their post-depositional developments. The occurance of lenticular bedding indicate a minor flow. Minor in both the sense i.e. in intensity and duration.

The above model respesents a fining upward sequence with respect to the grain size as well as in the scale of sedimentary structure produced due to a progressive decline in the current competency at the time of their formation (Fig. 16).

M O D E L - B

Model B shows the genetic sequence of sedimentary structure morphotypes develo ed in braid bars of the Ganga river. The sequence starts with large scale trough cross-stratifications developed in coarse sand. Some micaceous coarser material also found to arrange along the foresets of the cross-stratifications.

This structure morphotype is overlain by horizontal stratifications developed exclusively in very well sorted sand. The horizontal stratifications followed upward by large scale planar cross-stratifications and in turn by ripple drift cross laminations passes upwards into convolute laminations and then into small scale trough cross-stratifications. The top of the sequence is makred by clay and silt owing parallel laminations.

Thus the sequence starts with large scale trough cross stratifications and ends with the parallel laminations exhibits an ideal example of the fining upward sequence (Fig.17). Large scale cross-stratifications are confined to coarse sands while the small scale cross-stratifications developed in medium to fine sands. Horizontal stratifications developed in medium to sorted medium grained sand whereas, ripple drift laminations, parallel laminations and convolute laminations developed in fine sand and silt.

Apart from the indication of upward fining, the proposed sequence also reflects the formation of various structure morpho-types due to change in the intensity of the flow prevailing at the time of their formations. Large scale cross-stratifications are supposed to form in the upper part of lower flow regine (Simon and Richardson,1963). The horizontal stratifications have been related to the upper flow regime-most probable to the lower part of the upper flow fegime in which, plane beds are formed. Th ripple drift laminations indicate slow velocity with simultaneou deposition from suspension. The presence of parallel laminations at the top indicate zero velocity with deposition exclusively from suspension. The occurrence of convolute laminations in between ripple drift laminations and small scale trough cross-stratifications gives the clue about the hydrodynamic conditions existing at the time of their develoment. The presence of convolute laminations indicate the deformation of the upper part of ripple drift laminations into convolute laminations, as a result of the force exerted by the load of upper coarse grained trough cross-stratifications.

The proposed models developed are exclusively for Ganga river deposits. The general applicability will only be understood after detailed study and comparison with other modern and ancient braided systems.

C H A P T E R - VII

CONCLUSION

The river Ganga is the greatest river of northern India running from Gangotri to bay of Bengal (1550 miles). It deposits vast quantity of sediments in the form of braid bars, point bars, natural levees, overbank and flood plains. Under the area of investigation Ganga shows characteristically braided flow pattern carrying sediments of various size. Seven structure morphotypes have been recognised namely-cross stratifications. Ripple drift cross laminations, parallel laminations, Massive unit, Horizontal laminations, Distorted laminations and Lenticular bedding.

The cross stratifications - both planar and trough are the most abundant types structure morphotypes. They are produced by the migration of sand ripples and due to downstream and lateral Growth of channel bars. The ripple drift cross laminationsare second in abundance and occur in two forms - one in which laminae are in phase and other in which laminae are in drift. Low current velocity and abundant supply of the suspended sediments are responsible for the formation of this structure morphotype. Parallel laminations occur in mud deposited from the suspension in quite and calm conditions. Whereas, the horizontal laminations developed in sands deposited inuupper flow regime. Apart from these structure morphotypes, there are other distorted laminations-i.e. convolute laminations and wavy laminations. Two types of convolute laminations present are - Type A and Type B. This structure morphotype is produced due to water squeezing and obstruction in the sudden increased current velocity. Wavy laminations are post depositional and produced due to unequal loading. Massive unit, which covers the large part of the deposits is regarded as post depositional structure. Lenticular bedding is an other structure morphotype produced due to short lived current carrying sands.

The distribution of dip azimuths of cross stratifications show variations in current direction from the general flow patterns due to the development of bar deposits. The grain size analyses show gradual and significant change in the downcurrent direction. By and large, the mean size decreases in the downcurrent direction. The coarse clasts dominently comprised of quartz, mica, feldspar, chlorite and amphibole and rock fragments. The minerals present in small quantity are anatase, Garnet, Zircon, rutile, epidote, spinel, tourmaline, casseterite and opaque minerals.

Using sedimentary structure morphotypes, grain size characteristics, and stratigraphic sequences has enables to reconstruct the depositional models for the Ganga river.

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